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Review Article

A Review of Push-Pull Technology's Effect on the Management of Fall Armyworms (*Spodoptera Frugiperda*) in Ethiopian Maize (*Zea Mays*) Production

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Abstract

The fall armyworm (*Spodoptera frugiperda*), an invasive pest first reported in Ethiopia in 2017, has emerged one of the most serious threats to maize production. Its high reproductive potential, polyphagous, and rapid spreading capacity has led to substantial crop loss and economic damage in Ethiopia. Reliance on existing pest management strategies based on synthetic insecticides are proving increasingly unsustainable due to the costs, pest resistance, access to crop protection products, and environmental damage associated with pesticides. Push-pull technology (PPT) has emerged as an agroecological innovation based on cropping maize with repellent intercrops (e.g. Desmodium species) and trap crops (e.g. Brachiaria or Napier grass) can also help partially draw and trap FAW to some extent. Recent evidence (within the 2020 to 2025 period) indicated that PPT can reduce fall armyworm infestation, reduce crop loss/damage, effectively promote natural enemy populations, improve soil health/quality, and increase household resilience. This review presents evidence from Ethiopia and more broadly across East Africa to disentangle mechanisms and pathways for effectively (and ineffectively) implementing PPT in Ethiopian maize systems. The review highlighted the potential for PPT in Ethiopia for sustainable fall armyworm management but acknowledged the need for strengthened institutional support, improved seed systems, and better integration into climate-smart agricultural pathways to facilitate future adoption.

Keywords

Push-Pull Technology, Fall Armyworm (*Spodoptera Frugiperda*), Maize Production, Integrated Pest Management (IPM), Ethiopia

1. Introduction

Maize (*Zea mays* L.) is the second most important cereal crop in Ethiopia after teff and grown on 2 million hectares and by approximately 10 million smallholder farmers [1]. It is critical to national food security, providing over 16% of the daily caloric intake, as it is vital for household consumption and livestock feed [2]. Maize production in Ethiopia faces numerous challenges, including continuous soil degradation, recurring drought, and pest infestations. Of the pests affecting maize, the invasive fall armyworm (*Spodoptera frugiperda*), continues to be one of the most damaging. The FAW was first reported in Ethiopia in 2017 and has been rapidly spreading across the three maize-producing regions [3]. FAW larvae consume maize leaves, tassels, and maize cobs, and yield loss estimates change from 20–50%, and more extremely, local

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failure of maize crops due to severe outbreaks [4]. The economic cost to Ethiopia is staggering; the economic cost of lost yield nationally is much more than USD 200 million per year [1]. FAW management in Ethiopia relied, at the beginning, upon chemical insecticides. The government and local agencies supplied subsidized targeted insecticides to farmers. However, pesticides pose a number of problems: high costs for smallholders, difficulty in accessing supply especially in remote areas, dangers to users, contamination of environments, and resistance in FAW populations [5]. Additionally, chemical control does not often include smallholders doing subsistence farming who cannot afford multiple applications. There's a clear case for alternatives if we can label them as sustainable. Push-pull technology (PPT), developed in East Africa by the International Centre of Insect Physiology and Ecology (ICIPE) and their partners all evidence based, is established agroecological management method to control infestations of stemborers and striga weed respectively, and which has more recently suppressed infestations of FAW [6]. In Ethiopia, pilot studies and on-farm trials show that not only does PPT reduce FAW infestation; the system provides multiple co-benefits, including improved soil fertility, fodder and improved resilience to shocks at the household level [2]. This review collates evidence from 2020 to date to explore the impacts of push-pull technology in managing FAW in maize production in Ethiopia. This will specifically (i) address the biology and impact of FAW in Ethiopia; (ii) will detail the ecological principles of push-pull; (iii) industry and academic evidence around its effectiveness; (iv) co-benefits of its adoption; (v) barriers and opportunities which may constrain adoption; (vi) research gaps and priorities for policy.

2. Biology and Impact of FAW in Ethiopia

2.1. Biology and Feeding Behavior of FAW

The fall armyworm is a noctuid moth that originated in the Americas but is now invasive in more than 80 countries [7]. Its success as an invasive pest is attributed to its exceptional biological characteristics. For example, adult moths are very mobile, often flying greater than 100 km in a night, expanding its geographic range very quickly. The females can produce between 1,000–2,000 eggs in their lifetime which are typically laid in clusters on the undersides of maize leaves [6]. The larval stage is more damaging. FAW goes through six instars; later instars (4th–6th) are more damaging, and larvae feed voraciously on maize whorls, tassels, and developing ears. The infested plants will exhibit ragged leaf edges, possible window panning damage, and frass in the whorls. Heavy infestations will lead to dead hearts and poor filling of grains [3]. In Ethiopia farmers in Oromia, Amhara, and Tigray are describing crop devastation after FAW invasion, especially during the main rainy season when FAW pressure is high.

2.2. Socio-Economic Impacts of FAW in Ethiopia

The socio-economic impact of FAW in Ethiopia is significant. As stated by [1], FAW incurs annual national yield losses of more than USD 200 million, compromising both food security and rural livelihoods. The economic consequences of FAW are tending to hit hardest the poorest, smallholder farmers who cannot afford even effective ways to manage FAW. In the Tigray and Oromia regions, [4] reported that smallholder farmers were spending as much as 15% of their annual household income on pesticide based methods to manage FAW, often to the detriment of other household priorities. In addition, relying on pesticides exposes farmers and their family members to adverse health effects which range from skin irritations and breathing issues to pesticide toxicity [5]. FAW impacts go beyond direct economic losses and exacerbate Ethiopia's vulnerability to food insecurity. Maize accounts for nearly 20% of the calorie intake for rural households, and declines to maize harvests result in declines in food availability [2]. FAW outbreaks also strain government budgets because they require public sector agencies to tap into already limited resources to purchase pesticides for emergencies and needed distribution.

2.3. Push–Pull Technology Concept and Components

Push complex (i.e. push-pull technology, PPT) is a new intercropping system to suppress insect pests and parasitic weeds while improving soil fertility and providing fodder for livestock. It was initiated in the late 1990s by the International Centre of Insect Physiology and Ecology, ICIPE (Nairobi, Kenya) and Rothamsted Research (UK), and adopted across East Africa. This continuing process is also adapting climate-smart options for further innovative crop combinations. The concept of push-pull technology is straightforward but ecologically sophisticated, creating a balanced push-pull system that uses companion cropping to manipulate pest-plant interactions. It includes three components; push crops, generally Desmodium spp., are planted to repel a group of insect pests (stemborer moths) and suppress the parasitic weed Striga hermonthica from invading the maize and suppressing its growth through allelopathic root exudates; pull crops, typically Brachiaria or Napier grass used to attract moths to lay eggs into the crop, yet are not conducive for larval grazing and development; and maize as the target crop, which is enriched from reduced pest (and parasitic weed) pressure, soil fertility and the plants increased resilience to climate stress. The approach taken with push-pull technology is to exploit chemical ecology to suppress one or more key pests; it also not only suppressed major pests, but improved biodiversity and increased overall fodder availability for livestock, and became the single most successful sustainable pest management innovation throughout sub-Saharan Africa [8-11].

2.3.1. Push Component: Desmodium and Repellence

The push component of PPT involves perennial legumes in the genus Desmodium. These species produce volatile organic compounds (VOCs) like (E)-ocimene and (E)-4, 8-dimethyl-1, 3, 7-nonatriene (DMNT) and repel oviposition FAW moths from maize [6]. Among other studies, there is evidence that maize intercropped with Desmodium intortum has significantly fewer egg clusters, compared to maize monocropped. In addition to repelling FAW, it has been shown that Desmodium improves soil fertility through nitrogen fixation, improves erosion risk, and suppresses the parasitic weed Striga hermonthica through allelopathic root exudates [5]. These multiple functions make Desmodium an important feature of agroecological intensification in Ethiopia's smallholder systems.

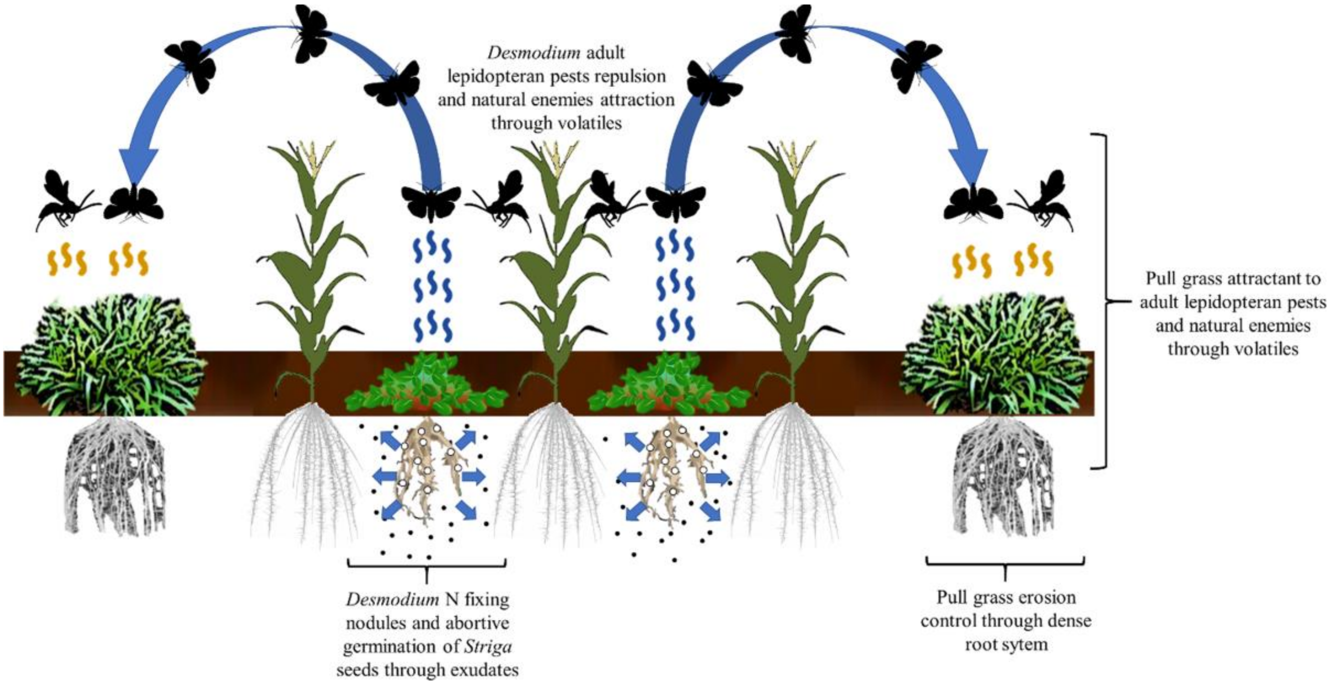

Figure 1. *Push-pull technology of maize [5, 3].*

2.3.2. Pull Component: *Brachiaria* and Napier Grass Border Crops

In the pull component, trap crops like Brachiaria spp. or Napier grass (Pennisetum purpureum) can be planted as border rows. FAW moths will be attracted to these grasses for oviposition, but once the eggs hatch, the potential for survival of the subsequent larvae is extremely low due to properties of the plant which prevent feeding and development (3). Effectively, these crops are “dead-end” hosts by concentrating FAW populations away from maize fields. Brachiaria grasses also build soil health and are able to provide high-quality fodder for livestock, further strengthening the integration of cropping and livestock practices. Climate-smart varieties like Brachiaria cv. Mulato II are particularly well-suited for the dry lands of Ethiopia [12].

2.4. Mechanisms and Ecological Principles of Push–Pull Technology

One of the lesser-known yet very important aspects of PPT is the increased potential for restoring biological control as natural enemy populations are supported and possibly enhanced. Desmodium intercrops and Brachiaria border rows provide habitat, food, and shelter for natural enemies like parasitoid wasps (Cotesia icipe, Telenomus remus) and predators like ladybird beetles and spiders [6]. Sobhy et al. (2022) reported that PPT plots had significantly higher rates of parasitism of FAW larvae compared to mono-cropped maize [6]. This ecological intensification may help reduce reliance on pesticides while also restoring biodiversity within maize systems.

Push-pull technology is an environmentally-based cropping system that utilizes pest behavior, and the agro ecosystem to minimize pest pressure, and enhance/maintain crop yield and productivity. Push-pull technology uses three tactical components: (1) a repellent intercrop (push) located amid linear maize rows, typically Desmodium spp. (legume); (2) attractive border/trap crops (pull), typically Brachiaria spp. (grass) or Napier grass, to distract oviposition moths away from, the maize crop; and, (3) agronomic practice that complements fertility-enhancing, and fodder-enhancing management. Push-pull is based on chemical ecology: changes in volatile emissions, from companion plants, change pest olfactory host-seeking, and oviposition, decisions, whilst concurrently enhancing natural-enemy attraction. The multiple dimensions of the push-pull technology system: behavioral change (repelling/attracting), bottom up effects (plant vigor, allelopathic), and, top down control (enhanced parasitoid/predator), provide a multi-tiered action to disrupt pest populations.

2.5. Experimental and On-Farm Evidence in Ethiopia

Push–Pull Technology (PPT) has been evaluated intensively in East Africa as a climate-smart strategy for the management of Fall Armyworm (FAW) in systems of maize. The studies used drought-tolerant cultivars of Desmodium species and Brachiaria species demonstrated a significant suppression of FAW populations generally from a combination of repellent intercrops and attractive trap crops [6, 13]. All experimental trials across multiple agroecological zones and climatic conditions resulted in a larval abundance that was reduced by 45-70% compared to a mono-cropped maize (*Zea mays*); when reductions in foliar and ear damage were assessed in both systems, maize with PPT not only significantly reduced pest populations but also had yield increases between 25-40%, the effective outcome of PPT was to both manage the pest while enhancing productivity [3]. Particularly by adapting planting arrangements, cultivar and spacing recommendations were tailored to accommodate local conditions of precipitation and temperature variability, climate-smart PPT has been resilient in terms of varying rainfall or temperature even under extreme and variable precipitation programs both at the highest longitudes of the eastern African highland and at longer latitudes in semi-arid maize-growing regions. This body of evidence further substantiates the evidence supporting the hypothesis that PPT has strong potential to be an environmentally sustainable, scalable option over insect-dependent management strategies [14].

PPT's effectiveness has been validated in Ethiopia with controlled field trials and participatory on-farm studies. Trials in northern Ethiopia, especially Tigray (Hawzien Woreda), observed large reductions in FAW egg-laying and larval densities in maize grown as intercrop with Desmodium edged with Brachiaria or Napier grass. Foliar damage assessments determined that PPT plots resulted in 40–60% less leaf injury scores than conventional mono-cropped fields, and ear damage was also reduced. Farmers who participated in the on-farm demonstrations also reported yield gains around 30% above local monocrop practices. Additionally, inclusive tools such as pheromone or light traps to monitor adult FAW complemented PPT by providing options for threshold methods of pest intervention, reducing pesticide utilization, and Labour efficiency. Education process of learning has resulted in outcomes, social and institutional channels for facilitating dissemination of PPT occurred in the participatory adoption studies. Farmer field schools and localized demonstration plots were key methods for knowledge transfer to grow crops outside of previous monocrop traditions. The impact of effective extension services enabled farmers to receive support and training for the technical standards and procedures to establish intercrops, plan suitable spatial arrangements, and manage the grazing grazing regulations for management. Adoption was encouraged further by the knowledge of the multiple co-benefits of EPC; considering social capital, improving soil fertility over time, fodder of good quality for livestock and even selling the biomass generated. These findings suggest that PPT is not only an effective FAW management tool but also an agroecological integrated strategy that enhances resilience, productivity, and livelihood outcomes for Ethiopian smallholders [14, 5].

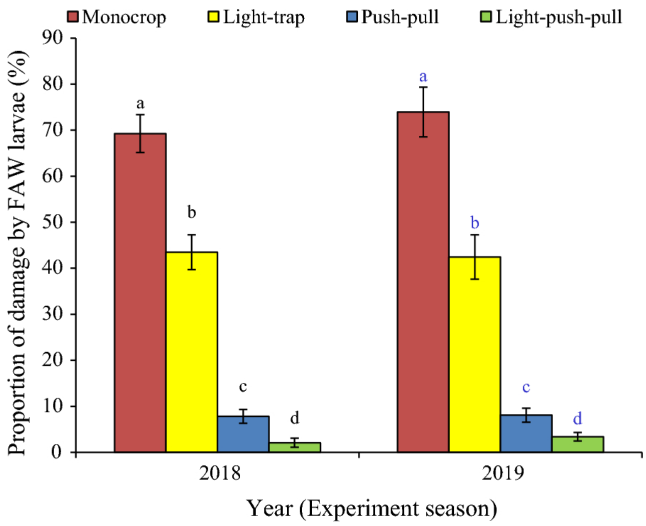

Figure 2. *Field trails push-pull technology [5].*

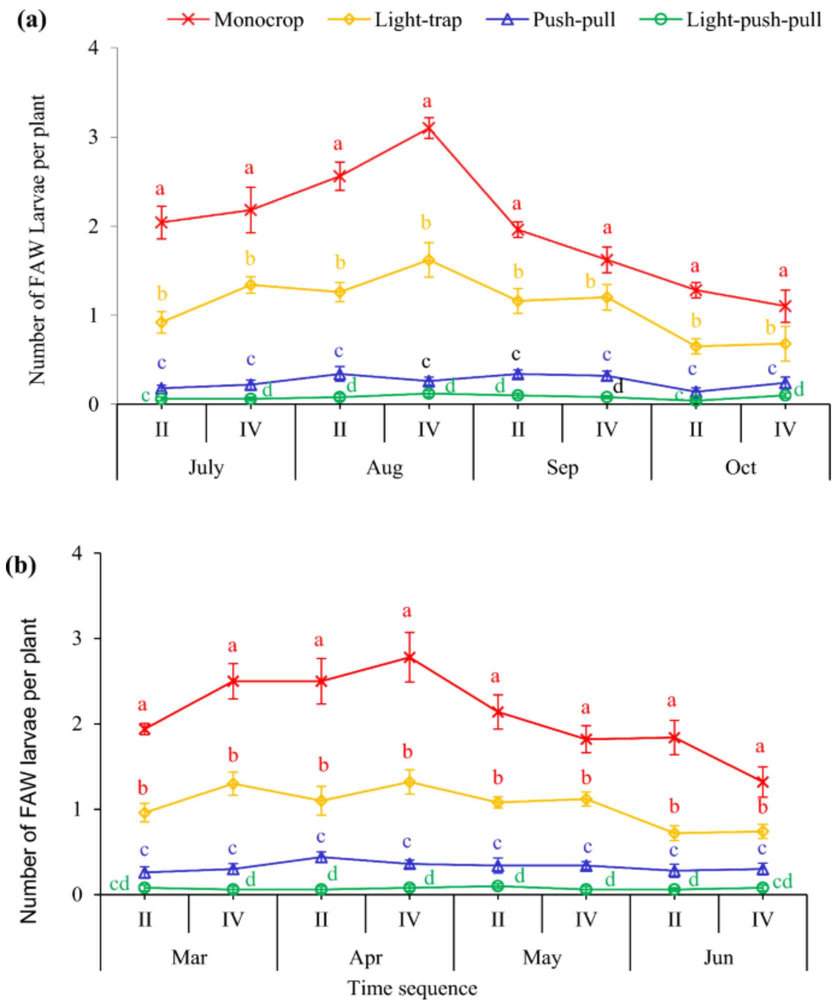

Figure 3. *Field trails push-pull technology [5].*

The development of Push–Pull Technology (PPT) is a great advance for smallholder FAW management with the addition of monitoring techniques using pheromone and light traps. These tools will enable farmers to adopt informed threshold-based interventions to limit unnecessary pesticide applications while remaining effective in pest suppression [13]. Field trials in Ethiopia have indicated that PPT plots with light-traps or pheromone traps maintained lower densities of eggs and larvae across maize growth stages than PPT plots without traps. This illustrates a beneficial complementarity from animal behavior manipulation with real-time population monitoring [3]. In addition, farmer scouting and monitoring tools offered timely identification of outbreak hotspots to optimize place and time to supplement farmer resources while recognizing a reduction environmental footprint. The use of PPT with monitoring tools, and participatory farmer practices was an example of an ecologically and economically optimized triplet proposition fit for smallholder maize systems [14].

2.6. Mechanistic Insights: Chemical, Physiological, and Soils Interactions

The effectiveness of PPT depends on plant-mediated chemical cues that alter FAW behavior. Electrophysiological studies and bioassays have empirically confirmed that Desmodium spp. emitted VOCs that repel oviposition FAW moths. On the other hand, Brachiaria and Napier grass VOCs attracted oviposition females that made them a preferred oviposition site [3, 6]. Desmodium spp. VOCs also act as kairomones increasing parasitism by natural enemies of FAW like Cotesia icipe and Telenomus remus contributing to top-down control of the FAW pest management regime. Strong mechanistic principles show the basis of crop selection for PPT, and to inform breeding programs (cultivar) to enhance VOCs for regional FAW ecotypes [13].

PPT systems can also promote bottom-up resistance through the improved physiology of plants. Having Desmodium intercrops improves soil fertility and moisture species for supporting higher vigor in maize [5] and better resistance to FAW losses. Expectedly, maize grows with greater vigor due to more soil nutrients and moisture and because maize grown in PPT systems has been reported to generative induced resistance through greater expression of anti-herbivore secondary metabolites, including secondary metabolites within the family of benzoxazinoids, that suppress herbivory by reducing larval feeding and larvae growth [12].

These induced defenses of maize complement the behavioral push/pull mechanisms that integrate low-cost, more stable agricultural resilience and yields with reduced pressure from herbivores.

Utilizing PPT for long periods will enhance soil health and modify the dynamics of soil microbial community above and below ground level. Intercropped Desmodium improves nitrogen fixation while Brachiaria provides ongoing ground cover, which along with choices on which species to plant each season, increases organic carbon and enhances nutrient cycling [6]. Data from microbial community studies of soil micro-biome support the idea that PPT plots are more diverse in the rhizosphere than conventional or mono-cropped maize, and this biodiversity is favorable for health and durability of all plants in agro system in the context of environmental perturbations arising from abiotic stresses such drought or nutrient limitation [13]. The accumulation of changes in the physical and chemical properties of soils not only supports maize yield, it also increases the agro system's ability to buffer pest outbreaks, climate variability and other environmental perturbations. In sum, the application of PPT provides systemic health benefits to an agro system - which is far beyond the ability to uniquely control pest cleanly and sustainably within the context of an agro system [3].

2.7. Agronomic Co-Benefits and Livelihood Impacts

Push-Pull Technology (PPT) delivers significant co-benefits to those engaging in mixed crop-livestock systems, especially when considering the potential for fodder provision. PPT encourages the use of Brachiaria and Desmodium species, which can produce good quality biomass that may be harvested for cut-and-carry fodder, greatly improving the nutrition and productivity of livestock [6, 3]. Introducing fodder crops into smallholder farming systems also helped close some nutrient cycles as maize farmers were able to return the manure from livestock to their fields, improving soil fertility and crop performance [13]. The links between crop and livestock offered by PPT further enhanced the perceived value of the technology, and provided farmers with the motivation to take up and sustain the practice. This was especially effective in resource-poor contexts, where having alternative land use opportunities is essential [14].

PPT impacts soil fertility through several different pathways. Desmodium, a legume intercrop, in particular fixes atmospheric nitrogen, creating a source of nutrients for soil [5]. The canopy and groundcover created by Desmodium and Brachiaria also reduce erosion, build organic matter, and improve soil structure, which in turn increases nutrient cycling and water retention [12]. Large scale longitudinal field trials conducted in Ethiopia have demonstrated that maize yields under PPT steadily increase as production scales from one to five years, when compared with unimproved mono-cropped systems - this difference is due to not only reduced pest pressure, but the improved soil fertility too. These findings also show PP as suitable example of sustainable intensification that addresses pest management and soil health simultaneously rather than simply as an alternative to chemical control [6, 13].

PPT helps to offset FAW damage and supports a higher, stable maize yield, adding to the household food security and resilience of Ethiopian smallholder farming systems. The additional fodder, soil fertility, and ecosystem services also provide a diversified income and nutrition stream to help mitigate the vulnerability to climatic and pest shocks [3]. Evidence from!! Adoption studies in northern and eastern Ethiopia supports that households that have adopted PPT have better food availability solids and have reduced exposure to risk compared to the risk associated with conventional monocropping systems [13]. Despite these benefits, rigorous longitudinal socio-economic studies, particularly in assessing the longer-term impacts on livelihoods, gender equity, and pathways of resilience, are not abundant. Thus, more research is needed on these linkages.

2.8. Adoption, Constraints, and Institutional Support

Three primary mechanisms have spurred PPT uptake in Ethiopia: 1) actual pest suppression, 2) yield improvements, and 3) the many co-benefits of fodder provision and soil fertility improvement. ICIPE and CABI have provided active extension assistance, encouraging adoption through participatory farmer training and demonstration plots [14]. Farmer-to-farmer sharing of knowledge, as well as focused demonstration sites, help facilitate diffusion. Diffusion, as in the form of knowledge and technology transfer facilitated through social learning networks like ACT4EAT, has made spatial turnaround (the connection between farmers to transform acceptances into collaboration of pest control) possible, thereby helping to legitimize the technology [6].

While there are clear advantages of PPT limitations can still affect the uptake. First, access to good quality Desmodium seed and suitable Brachiaria cultivars is limited for many smallholders [3]. Second, establishing PPT requires increased Labour at the beginning of the planting season for planting, weeding, and grazing management, and knowledge regarding the best spatial arrangements and nursery management. Grazing animals freely can destroy intercrop and border plants; animals must be confining by cut-and-carry system or fences. In this instance, costs and perceived Labour input can cause resource-poor farmers to discount the system, despite considerable long-term benefits [13].

To overcome barriers to adoption, it is important to have institutional support. Seed systems, effective extension services, subsidies or input support during the transition years, and incorporation of PPT into national climate-smart agriculture and Integrated Pest Management (IPM) frameworks can support scaling [14]. ICIPE's documentation of demonstration and training programs with community-based seed multiplication ventures has highlighted success in Ethiopia in situ. If PPT could be recognized as part of climate-smart and nature-based solutions in policy dialogue, it could spur research funding, bring more inputs to the table, and provide an opportunity for broader adoption, leading to resilient maize systems among smallholders [13, 5].

2.9. Comparative Performance of PPT and other FAW Management Options

Push–Pull Technology (PPT) has been deeply compared to conventional insecticide-based tactics for managing Fall Armyworm (FAW) in maize. A number of studies have shown that PPT can achieve similar, or better, impacts on FAW infestation and foliar damage over the cropping season than pesticides, and co-benefits such as improved soil fertility, fodder production, and biodiversity can be added [6, 3]. Whereas broad-spectrum chemical control often aims to kill all FAWs here and now, and can ultimately lead to a cycle of resistance and non-target effects, the PPT tactics used do not fall into such broad targeting service, because PPT affects pest behavior through repellent intercrops (Desmodium) and attractive trap crops (Brachiaria/Napier), while suppressing pests sustainably and not negatively impacting natural enemies. Integrated approaches that allow the integration of PPT and monitoring tools (e.g. pheromone or light traps) with selective bio-pesticides can provide higher outcomes than either tactic alone [13, 14]. Behavioral control integrated with monitoring the population can allow farmers to take action when the population needed alarm for action is met (e.g. pesticide application). Distal outcomes mitigate for the overall reduction in amount of pesticide applied, reduce production costs, and reduce human and environmental exposure, but the populations of beneficial arthropods e.g. parasitoids and predators remain intact to allow them to provide a level of top-down pest suppression. Integrated like this promotes economic and ecological sustainability for smallholder systems, and builds resilient maize production systems. Notwithstanding the above, PPT is not the complete answer for all situations. There may still be instances of significant FAW population density, or partial implementation suggesting that localized (or spot) interventions with safer bio pesticides may still be needed to prevent major crop damage and loss [14, 6]. The addition of chemical or biological interventions supports a strong degree of confidence in the effectiveness of crop protection goal treatments while preserving, in the long run, the ecological and productivity benefits of adopting PPT. As a whole systems context, comparative studies advocate that PPT can be broadly considered a potent and environmentally sustainable alternative to conventional pesticides, and, as with all pest management interventions, particularly when used as part of a wider integrated pest management (IPM) process.

2.10. Recent Innovations, Research Gaps and Policy Recommendations

New trials in Ethiopia's dry land zones demonstrate that climate-smart Push-Pull Technology (PPT) is likely to provide effective Fall Armyworm (FAW) suppression under water-limited conditions. Since the initial publication about PPT, drought-tolerant cultivars of Desmodium and Brachiaria have been used to deliver consistent pest control while providing quality fodder for livestock [14]. Changes to the traditional PPT system by varying planting densities, adjusting spatial arrangements, and selecting cultivars having improved adaptability to soils and moisture, will enhance the system's resilience to variations in climate. These specific modifications extend the use of the PPT system, in marginal agro ecosystems with climatic and economic challenges, providing sustainable production options along with pest management for smallholder farmers [14, 6].

Chemical ecology advances have provided important new information concerning the effect of volatile organic compounds (VOCs) produced by Desmodium, Brachiaria and Napier grass on FAW behavior and natural enemies. VOC profiling allow selections and breeding for companion plant cultivars with the best volatile blends that increase FAW repellency or, attract parasitoids and predators [6]. Additionally, semi chemical-based tools like synthetic VOC dispensers and lures are now being explored as potential complements to PPT that may allow finer manipulation of pest behavior and enhanced IPM effects. These developments will enable push–pull systems to be customized against local pest ecotypes and local environmental circumstances with a view to improving the results and sustainability of FAW management by smallholders [6].

Farmers' uptake of PPT depend upon how they perceive ease of use, input access, and community norms [1, 2]. Participatory approaches (such as farmer field schools, locally led demonstration plots, and peer to peer learning) are proven to improve acceptance and uptake rates [1, 2]. The participatory approaches instill attitudes of trust in the technology, provide opportunities for social learning and facilitate normative support for the use of PPT in smallholder communities [1, 2]. Using interventions that marry technical innovations with culturally appropriate extension approaches ensures that the ecological and agronomic payoffs for PPT are realized in Ethiopia's diverse farming landscapes [1, 2].

While promising developments have been made, several knowledge gaps will limit wide and continued adoption of PPT [3, 2]. Long-term, multi-season studies are needed to assess the longevity of FAW suppression, stability of yield, and overall resilience of the system in the face of a variable climate [3, 2]. There is also very little household-level socio-economic work, including Labour allocation, gender differentiated impacts and cost-benefit trade-offs, limiting an understanding of adoption processes [3, 2]. Local seed multiplication and local distribution systems for Desmodium and

Brachiaria remain inefficiently developed, limiting access for smallholders [3, 2]. There is also a need for research investigating the potential synergies and antagonisms between PPT and the complementary IPM strategies being researched—such as: biological control agents, pheromone traps or selective bio-pesticides—to develop the most optimized integrated strategies for Ethiopia's diverse agro ecologies [1, 3].

To facilitate the uptake and scaling of PPT in Ethiopia, the following recommendations are made based on recent evidence [1, 2]: Scaling PPT in Ethiopia is a complex process that includes seed systems, farmer training, policy, integrated pest management, and research [1, 2]. Public–private partnerships, community seed enterprises, and NGO-distributed networks are necessary in order to ensure farmers obtain planting material of Desmodium and Brachiaria in time for successful adoption (seed banks are simply too far away for many farmers) [1, 2]. Participatory training and extension programs with demonstration plots and farmer field schools can enable farmers to acquire knowledge about early crop establishment, cut-and-carry management, and local cropping calendars. Then sufficiently capacitate farmers to successfully implement PPT [1, 2]. Expanding PPT into national IPM and climate-smart agriculture policies (CSAP), and climate-smart agriculture initiatives that include seed input support and targeted subsidies, and planting material for early adoption by farmers and agronomists, or early adopters raises the likelihood of successful adoption [3, 2]. Additionally, integrating PPT with monitoring technologies such as pheromone and light traps provides an opportunity for reduction of pesticide reliance and optimal pest suppression thresholds [1, 2]. Finally, supporting interdisciplinary research into the economics of PPT, gender issues for farmer participation, long-term implications in the agro ecosystem, and optimal cultivar encouraged using PPT is essential to improve recommendations, enhance adoption, and describe ongoing sustainable impacts at scale [1, 3].

3. Conclusion

Push-pull technology is an effective, science-backed, multi-functional method to manage fall armyworm in smallholder maize systems in Ethiopia. Mechanistic studies of plant volatiles and field work in East Africa and Ethiopia between 2020-2025 have produced ample evidence of strong behavioral repellence, trap crop attraction, increased natural-enemy activity, and agronomic co-benefits (soil fertility, fodder). When use with monitoring and a timely extension approach, PPT can decrease dependency on chemical insecticides while simultaneously increasing productivity and resilience. In order to effectively scale-up the implementation of PPT in Ethiopia will require coordinated efforts to strengthen seed systems, extension capability, policy enabling environment, and research knowledge gaps regarding long-term impacts, economics and gendered dimensions of adoption. Synthesis of evidence from 2020-2025 indicates that PPT represents not only a tool for pest management, but an integrated, climate-smart route to sustainable intensification of smallholder maize systems.

Abbreviations

IPM	Integrated Pest Management
VOCs	Volatile Organic Compounds
DMNT	Dimethyl- Nonatriene
CSAP	Climate-Smart Agriculture Policies
FAW	Fall Armyworms
PPT	Push-Pull Technology

Conflicts of Interest

The authors declare no conflicts of the interest.

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