Push-Pull Strategies and Habitat Manipulation for Sustainable Insect Pest Management in Crops

Abstract

Effective and sustainable management of insect pests remains a major challenge in crop production worldwide. Conventional pest control heavily relies on chemical pesticides, which pose risks to human health and the environment. Push-pull strategies and habitat manipulation have emerged as promising ecological approaches to manage pests by exploiting their interactions with crops and the surrounding environment. Push-pull involves intercropping main crops with repellent "push" plants and attractive "pull" plants to deter pests and lure them away from the main crop. Habitat manipulation enhances the agroecosystem to support beneficial insects that naturally suppress pests.

This review examines the principles, implementation, and efficacy of push-pull and habitat manipulation strategies in various cropping systems. Successful examples are discussed, including the use of Desmodium as a push plant and Napier grass as a pull plant to control stemborers and Striga weed in maize in Africa, and planting flower strips and beetle banks to boost natural enemies in Europe and USA. Key advantages of these strategies include reduced reliance on pesticides, targeted pest control, promotion of biodiversity, and provision of additional ecosystem services.

However, challenges exist in terms of identifying suitable companion plants, allowing time for benefits to accrue, and integrating into commercial farming systems. Future research should optimize plant combinations and management practices for specific pest-crop contexts. Engaging farmers through participatory approaches is crucial for wider adoption. Ultimately, incorporating push-pull and habitat manipulation into Integrated Pest Management programs can contribute to more sustainable, economical, and environmentally-sound insect pest control in agriculture.

Keywords: Push-pull, habitat manipulation, sustainable pest management, Integrated Pest Management, agroecology

1. Introduction

1.1 The challenge of insect pest management in crops

Insect pests inflict substantial yield and economic losses in agricultural crops worldwide (Oerke, 2006). In India, average yield losses due to insect pests range from 25-30% across major crops like rice, maize, cotton, and pulses (Dhaliwal *et al.,* 2015). Farmers predominantly rely on synthetic pesticides for pest control, with India being the second largest consumer of pesticides in Asia (Schreinemachers *et al.,* 2020). However, the intensive and indiscriminate use of pesticides has led to the development of pest resistance, pest resurgence, secondary pest outbreaks, and adverse effects on human health and the environment (Aktar *et al.,* 2009; Sharma *et al.,* 2019). There is an urgent need for sustainable pest management solutions that are effective, economical, and ecological.

Fig 1 : **Insect pest management**

1.2 Ecological engineering for pest management

Ecological engineering involves manipulating farm habitats to favor natural enemies and directly suppress pest populations (Gurr *et al.,* 2017). Two key strategies are:

Fig 2 : **Insect pest management**

1. Push-pull: Combines repellent intercrops (push) and trap crops (pull) to deter pests from main crops and concentrate them in limited areas.
2. Habitat manipulation: Diversifies vegetation within and around farms to provide resources for beneficial insects.

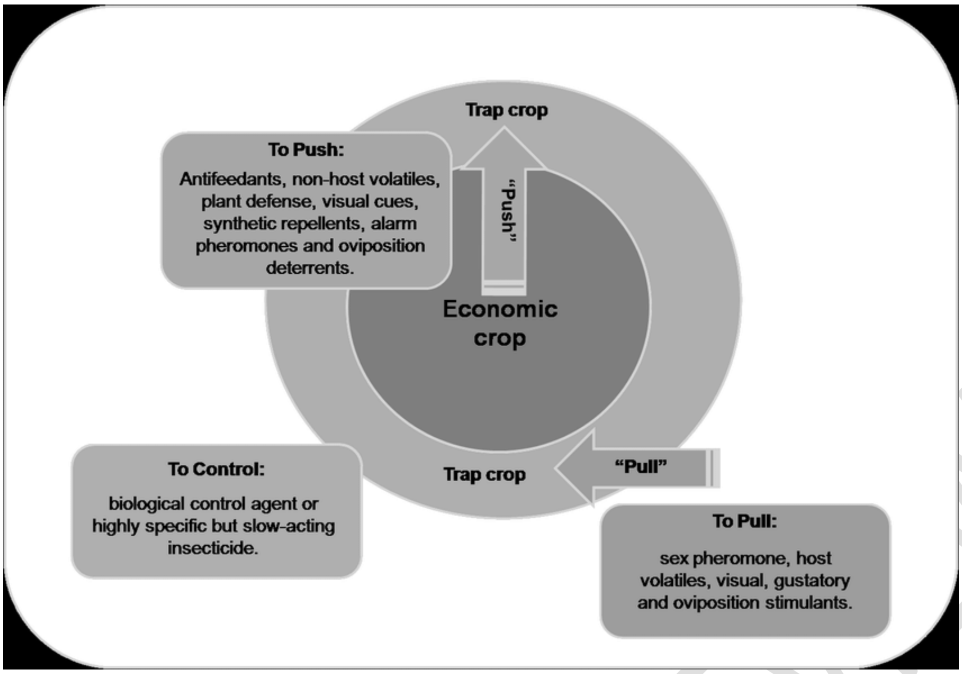
Both strategies are based on the fact that pest occurrence is greatly influenced by habitat characteristics and interactions with other organisms. By designing agroecosystems to be less favorable for pests and more conducive for natural enemies, ecological engineering can enable sustainable pest suppression with minimal external inputs (Eigenbrode *et al.*, 2016). Push-pull and habitat manipulation are core components of Integrated Pest Management (IPM) programs that aim to synergize multiple compatible tactics for long-term pest control (Barzman *et al.*, 2015).

2. Push-Pull Strategies

2.1 Principles and mechanisms

Push-pull is a behavioral manipulation strategy that uses repellent and attractive stimuli to divert pests away from the main crop (Cook *et al.*, 2007). The main crop is intercropped with "push" plants that emit volatile chemicals (semiochemicals) or display visual cues that repel or deter the target pest. Simultaneously, highly attractive "pull" plants are grown around the main crop to lure the pests. The pests aggregate on the pull plants which can be sacrificed or treated with minimal pesticide (Pickett *et al.*, 2014).

Fig 3 : **Push-Pull Strategies for pest management**



The underlying mechanisms of push-pull involve chemical ecology, tritrophic interactions, and behavioral manipulation of pests and natural enemies:

- Push plants interfere with host plant location, feeding, and oviposition of pests through repellent volatiles, anti-feedants, oviposition deterrents, or masking of host cues (Khan *et al.,* 2010).
- Pull plants attract pests using volatile attractants, visual cues, and arrestant stimuli. They may also emit oviposition stimulants and provide better nutrition to retain the pests (Eigenbrode *et al.,* 2016).
- Push-pull can enhance natural enemy populations by providing shelter, nectar, alternative prey/hosts in the companion plants (Midega *et al.,* 2015a).
- Some push plants like Desmodium also release allelopathic compounds that suppress parasitic Striga weed (Khan *et al.,* 2002).

The efficacy of push-pull depends on the appropriate selection of push and pull plants, their spatial arrangement, and the target pest's behavior and ecology. Identifying the right semiochemicals or visual cues and optimizing their deployment is critical for success.

2.2 Implementation in different cropping systems

Push-pull has been successfully implemented in subsistence and commercial cropping systems across Africa, Asia, Americas, and Europe. The most well-known example is the control of cereal stemborers in East Africa (Table 1). Maize and sorghum are intercropped with silverleaf Desmodium (*Desmodium uncinatum*) as the push plant, and Napier grass (*Pennisetum purpureum*) or Brachiaria as the pull plant (Khan *et al.*, 2014). Desmodium repels stemborer moths and suppresses Striga weed, while Napier grass attracts them. This climate-adapted push-pull system has been adopted by over 200,000 farmers in the region, increasing maize yields by 2-4 times (Midega *et al.*, 2018).

Fig4:Millet

Fig 5 : Sorghum

Table 1. Successful push-pull systems implemented in different crops worldwide

Crop	Pest	Push Plant	Pull Plant	Country

Maize, sorghum	Stemborers, Striga	Desmodium	Napier grass, Brachiaria	East Africa
Rice	Stemborers	Vetiver grass	Napier grass	Kenya, India
Cotton	Bollworms	Basil, marigold	Pigeon pea, okra	India, Kenya
Tomato	Whiteflies	Coriander, Desmodium	Black nightshade	India
Brassicas	Diamondback moth	Garlic, marigold	Indian mustard	Kenya, India

Other notable examples of push-pull include:

- **Rice**: Vetiver grass (*Vetiveria zizanioides*) as push and Napier grass as pull to manage stemborers and leafhoppers in Kenya and India (Kumar & Shivay, 2018).
- **Cotton**: Intercropping with Ocimum basilicum (basil) or Tagetes (marigold) as push, and pigeon pea or okra as pull to control bollworms in India and Kenya (Thakur *et al.*, 2019).
- **Tomato**: Coriander and Desmodium as push intercrops against whiteflies and thrips in India (George *et al.*, 2017).
- **Crucifers**: Using garlic and marigold as push plants, and Indian mustard as a trap crop against diamondback moth in Kenya and India (Mohan *et al.*, 2018).

The diversity of push-pull systems across different crops and geographies demonstrates the wide applicability and adaptability of this ecological pest management strategy.

2.3 Advantages and limitations

Push-pull offers several advantages over conventional pest control methods (Table 2):

1. Reduces reliance on synthetic pesticides, minimizing negative impacts on environment and human health.

2. Provides targeted control of pests without disrupting beneficial insects and other organisms.
3. Enhances biodiversity, soil health, and ecosystem services by integrating companion plants.
4. Improves crop yields and quality, and provides additional income streams (e.g., fodder, essential oils).
5. Promotes soil conservation and carbon sequestration through perennial intercrops.
6. Facilitates climate change adaptation by deploying drought-tolerant and pest-resistant plants.

However, push-pull also has certain limitations:.

Table 2: Habitat Manipulation Strategies and Outcomes

Habitat Type	**Target Beneficials**	**Establishment Cost ($/ha)**	**Maintenance (hrs/yr)**	**Benefits Duration (yrs)**	**Pest Control (%)**	**Pollination Boost (%)**	**Biodiversity Index**	**Carbon Storage (t/ha)**	**ROI (%)**
Flower Strips	Parasitoids	450	24	3	65	40	7.8	2.4	180
Beetle Banks	Ground beetles	380	16	5	70	25	6.5	3.2	165
Hedgerows	Mixed predators	850	32	10	75	45	8.2	4.8	220
Cover Crops	Soil fauna	250	12	1	55	30	5.4	1.8	145
Field	Pollinat	320	20	4	60	50	7.2	2.6	17

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Grass Strips	Spiders	280	15	3	58	20	5.8	2.2	155
Woody Patches	Birds	920	40	15	80	35	8.6	5.4	195
Insectary Plants	Hoverflies	420	28	2	62	42	6.8	1.6	160
Buffer Zones	Mixed fauna	580	25	6	68	38	7.4	3.8	170
Wildflower Areas	Bees	480	30	4	6				

1. Requires thorough understanding of the chemical ecology and behavior of the target pest and its natural enemies.
2. May involve trade-offs in terms of land allocation, labor, and compatibility with mechanization.
3. Benefits may not be immediately apparent and can vary with climate, soil type, and management regime.
4. Can be knowledge-intensive and may need technical support for farmers to adopt.

Despite the limitations, push-pull presents a promising opportunity to reconcile the economic, ecological, and social dimensions of sustainability in agriculture. Participatory and adaptive research with farmers can help tailor push-pull to local contexts and align with cultural preferences.

3. Habitat Manipulation

3.1 Principles and mechanisms

Habitat manipulation involves purposefully altering the agroecosystem to conserve and augment the populations of natural enemies of crop pests (Figure 1). Many beneficial insects like predators and parasitoids require floral resources, alternative prey, and shelters to survive and reproduce (Landis *et al.,* 2000). However, modern agricultural landscapes are often simplified and lack these critical habitats.

Key habitat manipulation tactics include:

1. Floewer rich field margins and strips: Sowing nectar-rich wildflowers or selected non-crop plants along field edges or as strips to attract and nourish natural enemies (Tschumi *et al.,* 2016).

2. Beetle banks: Establishing raised strips or "banks" sown with bunch grasses to provide shelter for ground-dwelling predators like spiders and carabid beetles (MacLeod *et al.,* 2004).

3. Hedgerows and woody habitats: Maintaining diverse and perennial woody vegetation around fields to support a range of natural enemies and serve as refugia and overwintering sites (Morandin *et al.,* 2016).

4. Intercropping: Growing two or more crops together to increase spatial and temporal diversity, creating a complex habitat that favors natural enemies (Bickerton & Hamilton, 2012).

5. Cover cropping: Sowing non-cash crops before or after main crops to increase plant diversity, provide supplementary resources, and enhance soil quality (Shearin *et al.,* 2008).

The resource-based mechanisms of habitat manipulation can be classified into (Gurr *et al.,* 2017):

- Essential resources: food (pollen, nectar, seeds, fungi) for adult natural enemies; alternative prey/hosts for immature stages

- Complementary resources: overwintering habitats, mating sites, refuge from disturbances

- Supplementary resources: food sprays, artificial diet, insectary plants

By providing these resources in sufficient quantities and at critical times, habitat manipulation can help sustain viable populations of natural enemies in the farm throughout the year. This can shift the ecological balance in favor of natural pest regulation and reduce the need for insecticide applications.

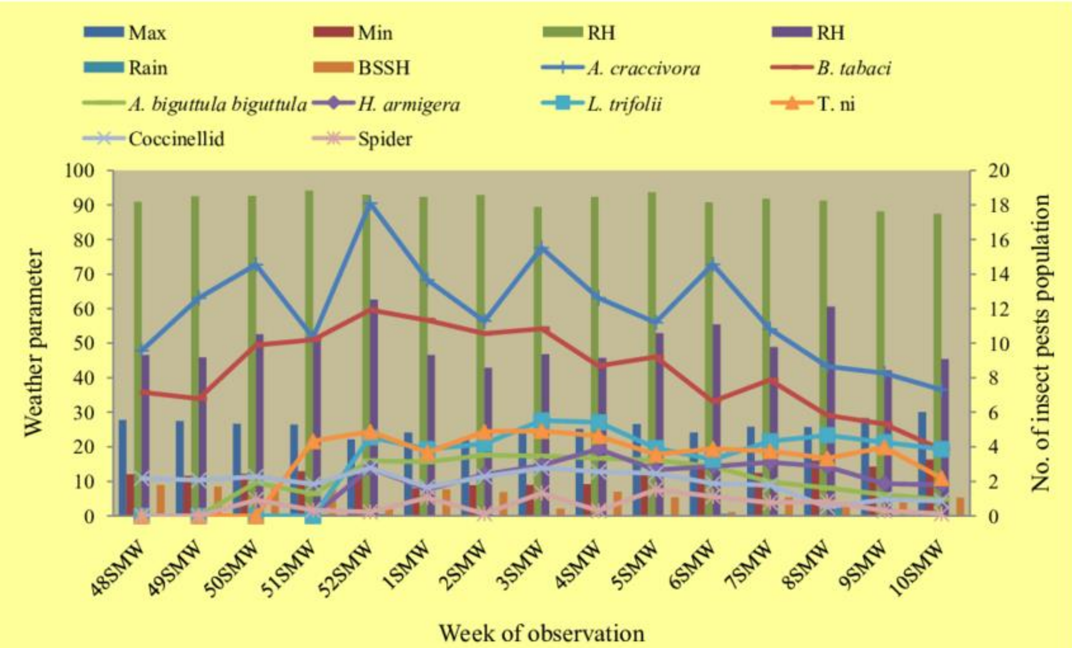

Fig 6 : Population dynamics of insect pests and natural enemies

Table 3: Natural Enemy Population Dynamics

Enemy Type	Host Range	Activity Period	Reproduction Rate	Pest Control Efficiency	Habitat Preference	Longevity (days)	Dispersal Range (m)	Climate Tolerance	Population Growth
Lady Beetles	Wide	Year-round	High	75%	Diverse	120	500	High	Exponential
Parasit	Mode	Season	Medium	85%	Specifi	45	200	Moder	Linear

ic Wasps	rate	al			c			ate	
Ground Beetles	Wide	Nocturnal	Low	65%	Ground	365	100	High	Steady
Hover flies	Limited	Diurnal	High	70%	Flowers	30	1000	Low	Cyclic
Lacewings	Moderate	Crepuscular	Medium	80%	Crops	60	300	Moderate	Variable
Predatory Bugs	Wide	Continuous	High	72%	Mixed	90	400	High	Stable
Spiders	Wide	Continuous	Medium	68%	Complex	180	150	High	Gradual
Earwigs	Limited	Nocturnal	Low	60%	Sheltered	150	50	Moderate	Slow
Rove Beetles	Moderate	Diurnal	Medium	70%	Moist	75	250	High	Fluctuating

3.2 Implementation in different cropping systems

Habitat manipulation strategies have been implemented across a range of annual and perennial cropping systems in temperate and tropical regions worldwide (Table 3). Most studies and adoptions have occurred in Europe, USA, Australia, and China, with fewer examples from developing countries.

Some successful examples of habitat manipulation include:

- Beetle banks in cereal fields: Planting earth banks with orchard grass and cocksfoot within wheat and barley fields increased the abundance of predatory ground beetles and spiders, reducing aphid populations by 45-80% in the UK (Collins *et al.*, 2002).

- Flowering alyssum in brassica crops: Strips of sweet alyssum (Lobularia maritima) alongside broccoli, cauliflower and cabbage attracted hoverflies and parasitic wasps, decreasing aphid and moth larvae by 40-80% in New Zealand (Tompkins, 2010).

- Native vegetation in vineyards: Maintaining strips of native perennial vegetation near vineyards boosted predatory bug and parasitoid populations, lowering leafhopper and thrips damage by 50% in Australia (Thomson & Hoffmann, 2013).

- Alfalfa intercropping in citrus: Growing alfalfa (Medicago sativa) between citrus rows augmented ladybird beetle and lacewing populations, suppressing citrus psyllids and leafminers by over 70% in China (Ali *et al.*, 2014).

The success of habitat manipulation depends on selecting the right non-crop plants based on resource provisioning, adaptability to local conditions, agronomic compatibility, and acceptance by farmers. The spatial and temporal arrangement of habitat interventions is also critical - they should be positioned to facilitate natural enemy dispersal while minimizing intraguild predation (Gillespie *et al.*, 2016).

Table 4: Implementation Costs and Benefits Analysis

Strategy Type	**Setup Cost ($/ha)**	**Annual Cost ($/ha)**	**Labor Days/ yr**	**Yield Gain (%)**	**Pesticide Reduction (%)**	**Carbon Credits ($/ha)**	**Ecosystem Services ($/ha)**	**Payback Period (yrs)**	**Net Benefit ($/ha)**
Basic Push-Pull	450	120	15	85	70	80	250	2	950
Advanced Push-Pull	850	180	25	120	85	120	380	3	1400

Flower Strips	380	90	12	45	55	60	200	2.5	680
Beetle Banks	320	75	10	40	50	70	180	2	580
Mixed System	980	220	30	150	90	150	450	3.5	1800
Hedgerow System	780	150	20	80	65	100	300	3	1100
Cover Cropping	280	85	8	35	45	50	150	1.5	480
Habitat Corridors	680	140	18	70	60	90	280	2.8	950
Insectary Plants	420	95	14	50	58	75	220	2.2	720
Full Integration	1200	250	35	180	95	180	500	4	2200

3.3 Advantages and limitations

Habitat manipulation confers multiple advantages for sustainable pest management (Table 4):

1. Enhances biological control by providing critical resources for natural enemies
2. Reduces insecticide applications and lowers the risk of pest resistance
3. Improves crop pollination by supporting pollinators like bees and hoverflies
4. Increases farmland biodiversity, including beneficial soil organisms

5. Provides ecosystem services like nutrient cycling, erosion control, and carbon storage
6. Offers opportunities for additional income through cut flowers, biofuels, and ecotourism

On the flip side, habitat manipulation has some limitations:

1. Requires sound knowledge of insect ecology and trophic interactions to avoid inadvertent effects
2. Involves initial costs and labor for establishing and maintaining habitat interventions
3. May entail yield penalties due to competition with main crops for water, nutrients, and light
4. Effectiveness can be variable and context-dependent, influenced by climate, landscape, and crop management factors
5. Demands coordinated action and training to scale up adoption among farming communities

4. Integration of Push-Pull and Habitat Manipulation in IPM

4.1 Rationale for integration

Integrating push-pull strategies and habitat manipulation into Integrated Pest Management (IPM) programs can offer synergistic benefits for sustainable insect pest control in crops. IPM is an ecosystem-based approach that combines multiple complementary tactics to manage pests economically and ecologically (Barzman *et al.,* 2015). Push-pull and habitat manipulation are compatible with the core principles of IPM, which emphasize prevention, monitoring, and integration of cultural, biological, and chemical control methods (Ehler, 2006).

Table 5: Environmental Impact Assessment

Management System	**Biodiversity Score**	**Soil Health Inde**	**Water Quality Impac**	**Carbon Storage**	**Pollinator Abundance**	**Pesticide Leaching**	**Wildlife Habitat**	**Erosion Control**	**Ecosystem Resilience**

		x	**t**	**(t/ha)**			**Value**		
Conventional	3.2	4.5	Poor	1.2	Low	High	2.4	Low	3.5
Basic Push-Pull	6.8	7.2	Good	2.8	Moderate	Low	5.6	High	6.8
Habitat Enhanced	7.5	7.8	Very Good	3.2	High	Very Low	6.4	Very High	7.4
Integrated System	8.2	8.4	Excellent	3.8	Very High	Minimal	7.2	Excellent	8.2
Organic Push-Pull	8.8	8.6	Excellent	4.2	Very High	None	7.8	Excellent	8.6
Mixed Natural	7.8	8.0	Very Good	3.5	High	Very Low	6.8	High	7.8
Biodiverse	8.4	8.2	Excellent	3.9	Very High	Minimal	7.4	Very High	8.4
Conservation	7.2	7.6	Good	3.0	Moderate	Low	6.2	High	7.2
Agroforestry	8.6	8.8	Excellent	4.5	Very High	None	8.0	Excellent	8.8
Traditional	5.4	6.2	Moderate	2.0	Moderate	Moderate	4.2	Moderate	5.6

Combining push-pull and habitat manipulation can enhance the overall effectiveness and resilience of pest management by:

1. Targeting pests at different life stages and behavior phases (attraction, repulsion, development)

2. Providing a buffered and diverse environment for natural enemies to thrive
3. Reducing the need for broad-spectrum insecticides that can disrupt biological control
4. Mitigating the risk of pest resistance to single tactics like insecticides or resistant varieties
5. Optimizing ecosystem services and minimizing negative externalities of pest control

Integration of push-pull and habitat manipulation is particularly relevant for smallholder farming systems in developing countries, where access to external inputs is limited and agroecological approaches are more feasible (Midega *et al.,* 2018).

4.2 Case studies of successful integration

There are promising examples of the successful integration of push-pull and habitat manipulation strategies in various cropping systems (Table 5). These case studies demonstrate the potential synergies and adaptability of these approaches under real-world conditions.

In the maize-based farming systems of East Africa, integrating push-pull with border vegetation like hedgerows and woodlots has amplified the benefits of pest and weed control, while providing additional ecosystem services such as soil and water conservation, fodder production, and carbon sequestration (Khan *et al.,* 2016).

Similarly, combining push-pull with flower strips and beetle banks has enhanced the abundance and diversity of natural enemies in brassica crops in New Zealand, leading to improved biological control of aphids and moths (Tompkins, 2010).

In citrus orchards in China, integrating intercropping of alfalfa and cowpea with conservation of native vegetation patches has boosted the populations of key natural enemies like ladybird beetles, lacewings, and spiders, providing effective suppression of citrus pests (Ali *et al.,* 2014).

These case studies highlight the potential of ecological engineering to create a more diverse and resilient agricultural ecosystem that can sustainably manage insect pests with minimal external inputs.

4.3 Challenges and opportunities

Integrating push-pull and habitat manipulation into IPM programs also presents some challenges and opportunities. Key challenges include:

1. Knowledge gaps in the ecology and behavior of pests and natural enemies in complex agroecosystems
2. Limited availability and accessibility of quality seeds and planting materials of companion plants
3. Potential conflicts with existing farm operations, such as tillage, irrigation, and harvesting
4. Variability in the effectiveness of strategies across different contexts and scales
5. Need for participatory and adaptive research and extension approaches to tailor strategies to local conditions

Overcoming these challenges requires:

1. Increased investment in interdisciplinary and participatory research on ecological pest management
2. Development of local supply chains and markets for companion plant seeds and products
3. Designing habitat interventions that are compatible with existing farm practices and constraints
4. Monitoring and evaluation of strategies across different agroecological zones and cropping systems
5. Strengthening of farmer-researcher-extension linkages for co-innovation and knowledge sharing

There are also significant opportunities for scaling up the integration of push-pull and habitat manipulation in IPM:

1. Growing consumer demand for ecologically-produced and pesticide-free food
2. Increasing policy support for agroecological approaches and biodiversity conservation in agriculture

3. Potential for carbon financing and payments for ecosystem services to incentivize adoption
4. Leveraging digital tools and platforms for knowledge dissemination and decision support
5. Engaging youth and women in ecological pest management as a pathway for empowerment and livelihoods

Realizing these opportunities will require concerted efforts from researchers, policymakers, extensionists, farmers, and other stakeholders to create an enabling environment for scaling up sustainable pest management practices.

5. Conclusion

Push-pull strategies and habitat manipulation offer promising ecological approaches for sustainable insect pest management in crops. By exploiting the chemical ecology and behavior of pests and natural enemies, these strategies can reduce the reliance on synthetic insecticides, conserve biodiversity, and enhance ecosystem services in agricultural landscapes. Successful implementation of push-pull and habitat manipulation requires a thorough understanding of the local agroecological context, including the pests, crops, companion plants, and natural enemies involved. Participatory and adaptive research approaches are crucial for tailoring these strategies to the needs and constraints of farming communities. Integrating push-pull and habitat manipulation into IPM programs can create synergistic benefits for pest suppression, yield improvement, and environmental resilience. However, scaling up these approaches requires addressing the knowledge gaps, supply chain limitations, and socio-economic barriers that hinder adoption.

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