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Agroecological Approaches to Combat Pest Resistance

Umar Abubakar FAV

Independent Researcher, USA

Corresponding Author; **Umar Abubakar FAV**

Abstract

The widespread and repeated use of chemical pesticides and single-mechanism resistance traits has driven the evolution of resistant pest populations worldwide, eroding the long-term effectiveness of conventional pest control. Agroecological approaches—including habitat and crop diversification, biological control, push-pull strategies, and landscape-level management—offer alternative or complementary pathways to suppress pest populations while reducing the selective pressure that drives resistance evolution. This article reviews the empirical and theoretical evidence for these approaches, drawing on case studies from Sub-Saharan Africa and broader meta-analytic evidence, and considers how agroecological principles can be integrated with genetic resistance-management strategies for transgenic crops.

Keyword: Sāṅkhyaphilosophy, Three Kinds of Sorrow, Cessation of Grief,

Introduction

Pest resistance to pesticides and to insect-resistant transgenic crops is a persistent and growing threat to global crop protection. Agricultural intensification built around agrochemicals, monocultures, and intensive mechanization has raised productivity but has also driven biodiversity loss, environmental contamination, and pest resistance to insecticides (106). In response, there has been growing interest in ecologically based approaches—collectively termed agroecological pest management—that reduce reliance on any single control tactic and thereby slow the evolutionary pressure that produces resistance. This article examines the evidence for several major agroecological strategies and their role in combating pest resistance.

Habitat and Crop Diversification

One of the most extensively studied agroecological strategies is diversifying the plant composition of agricultural fields and landscapes—through intercropping, flowering strips, hedgerows, and crop rotation—to disrupt pest colonization and support natural enemies. A meta-analysis of 552 experiments across 45 studies found that diversification schemes such as intercropping and the inclusion of repellent or attractant companion plants produced significantly stronger herbivore suppression, natural-enemy enhancement, and crop-damage reduction than less diversified systems, although the same analysis noted a small negative effect on

yield in some cases because diversification reduces the density of the main crop (125). This body of evidence supports the "associational resistance" and "enemies" hypotheses: diverse plant communities make it harder for specialist pests to locate host plants and provide better resources for the natural enemies that prey on them.

At a broader spatial scale, landscape complexity—the amount of semi-natural habitat such as hedgerows and non-crop vegetation surrounding fields—has also been shown to influence pest regulation. A widely cited review found that natural pest control tends to improve in landscapes with greater habitat complexity, though the strength of this effect depends on the specific pest–enemy system and the scale at which diversity is measured (135). These findings suggest that pest suppression is not only a field-level phenomenon but also depends on how agricultural landscapes are structured at a wider scale.

The Push-Pull System: A Field-Tested Agroecological Model

One of the most thoroughly validated agroecological pest management systems developed for smallholder farming in developing countries is the "push-pull" technology developed for cereal stemborer and Striga weed control in East Africa. The system intercroops maize with desmodium, a repellent forage legume, while planting Napier grass as an attractive border crop; desmodium repels stemborer moths while

Napier grass draws them away from the maize, and desmodium simultaneously suppresses the parasitic Striga weed through allelopathic mechanisms (118). An on-farm evaluation across 14 districts in western Kenya, comparing push-pull plots with maize monocrop plots on the same farms, found significantly lower stemborer damage and Striga infestation, along with higher maize grain yields, on push-pull plots (115). Because the system relies on the ecological behavior of pests and their host plants rather than any pesticide with a specific mode of action, it does not select for resistance in the way chemical controls or a single-toxin transgenic trait would, making it a durable option for smallholder cereal systems.

Biological Control

Biological control—the deliberate use of natural enemies such as predators, parasitoids, and entomopathogens to suppress pest populations—is a central pillar of agroecological pest management and is increasingly recognized as a mutual priority for both organic and integrated pest management (IPM) systems (108). Diversified cropping systems based on polycultures or with permanent vegetation cover support the activity of natural enemies by providing shelter and alternative food resources, strengthening biological control services relative to simplified monocultures (106). Because biological control agents typically exert continuous, low-level pressure on pest populations through multiple and often shifting mechanisms, rather than a single chemical mode of action applied repeatedly, it is comparatively difficult for pests to evolve resistance to a diverse suite of natural enemies in the way they routinely do to a single insecticide.

Agroecology and Genetic Resistance Management in Transgenic Crops

Agroecological principles also intersect with the genetic resistance-management strategies used for insect-resistant transgenic (Bt) crops. Widespread reliance on Bt crops expressing a single toxin exerts strong selective pressure for the evolution of pest resistance (147). The principal strategy for delaying this resistance is the planting of non-Bt "refuge" areas near Bt fields, which preserve susceptible insects that can interbreed with any resistant individuals that arise, diluting the spread of resistance alleles through the population (147, 145). This refuge strategy is fundamentally an agroecological intervention: it deliberately maintains habitat and host-plant heterogeneity across the landscape to manage the evolutionary dynamics of the pest population, illustrating that agroecological and biotechnological pest management are not mutually exclusive but can be combined to prolong the effectiveness of both.

Limitations and Implementation Challenges

Despite this evidence, agroecological approaches face several practical constraints. Diversification-based pest suppression can come with yield trade-offs where diversifying crops displaces the main crop's planting density (125), and the effectiveness of plant diversification and landscape complexity varies considerably depending on the pest-crop system, spatial scale, and distance from the diversified habitat (130). Biocontrol strategies are similarly constrained by conceptual inconsistencies, scalability barriers, regulatory gaps, and the risk that pests can still evolve resistance to biocontrol agents if the same agent is used continuously and at scale rather than rotated (111).

Successful adoption of technologies such as push-pull also depends on sustained extension support, functioning seed and planting-material supply systems, and multi-stakeholder partnerships to scale the technology to large numbers of smallholder households (123).

Policy and Practical Implications

The evidence points to several practical principles for using agroecological approaches to manage pest resistance:

- **Diversify rather than rely on a single tactic.** Whether through intercropping, companion planting, or rotating biological control agents, reducing the uniformity of selective pressure on a pest population is central to slowing resistance evolution (125, 111).
- **Design at multiple spatial scales.** Field-level diversification and landscape-level habitat complexity both contribute to pest suppression and should be considered complementary rather than substitute strategies (135, 130).
- **Combine agroecological and genetic strategies where transgenic crops are used.** Refuge-based resistance management for Bt crops is itself an agroecological practice and works best when integrated with, rather than treated as separate from, broader habitat management (147).
- **Invest in extension and supply chains for successful models.** Technologies such as push-pull demonstrate strong on-farm results but require sustained institutional support to scale beyond demonstration sites (123, 115).

Conclusion

Agroecological approaches—spanning crop and habitat diversification, biological control, and validated field systems such as push-pull—offer effective and evolutionarily durable alternatives and complements to conventional, single-mechanism pest control. By distributing selective pressure across multiple, shifting control mechanisms rather than relying on a single pesticide or resistance trait, these approaches can slow the pace at which pests evolve resistance while often delivering yield and environmental co-benefits. Realizing their full potential requires attention to scale-dependent effectiveness, yield trade-offs, and the institutional support needed to move successful models from research trials to widespread farmer adoption.

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