



INTERNATIONAL JOURNAL OF

Organic Agricultural

RESEARCH AND DEVELOPMENT

*Advancing Sustainable Agriculture for
a Healthier Planet*

VOLUME

21

SPECIAL ISSUE



MAY, 2026



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AGROFORESTRY SYSTEMS AS ECOLOGICAL BUFFERS AGAINST PEST OUTBREAKS IN ORGANIC FARMING: A REVIEW

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ABSTRACT

The intensification of agricultural landscapes has precipitated unprecedented challenges in pest management, particularly within organic farming systems where synthetic pesticide inputs are prohibited. Agroforestry systems integrated land-use practices incorporating trees with crops and/or livestock have emerged as promising ecological infrastructures for buffering pest outbreaks through multifaceted mechanisms. This review synthesizes contemporary evidence examining how agroforestry systems function as ecological buffers against pest outbreaks in organic farming contexts. The study analyze the mechanistic pathways through which agroforestry mediates pest pressure, including top-down regulation via natural enemy conservation, bottom-up effects through microclimate moderation and resource dilution, and the enhancement of functional biodiversity. While substantial evidence supports the pest-suppressive capacity of agroforestry in perennial cropping systems, significant challenges constrain implementation, including tree-crop competition for resources, knowledge gaps among practitioners, economic barriers, and contextual variability in pest responses. This review proposes solutions addressing these challenges through strategic species selection, adaptive management protocols, policy incentives, and participatory research frameworks. The study concluded that agroforestry represents a viable nature-based solution for pest resilience in organic agriculture, though its efficacy depends on context-specific design principles and systemic support structures.

Keywords: agroforestry, organic farming, pest control, natural enemies, sustainable agriculture, biodiversity

INTRODUCTION

More farmers are switching to organic farming every year. Worldwide, over 76 million hectares are now farmed organically (Willer *et al.*, 2023). Organic farming avoids synthetic pesticides and fertilizers, which appeals to health-conscious consumers and helps protect the environment.

Modern industrial farming has made pest problems worse in many ways. Large fields of single crops create perfect conditions for pests to multiply rapidly. These simplified landscapes destroy the homes of beneficial insects, birds, and other creatures that naturally keep pests in check (Letourneau *et al.*, 2011). When these natural helpers disappear, pest populations can explode into damaging outbreaks.

Agroforestry offers a different approach. Instead of clearing all trees to plant crops, agroforestry intentionally keeps or adds trees to agricultural landscapes. These trees serve multiple purposes:

they provide shade, improve soil health, offer harvestable products like fruit or timber, and crucially for this review help control pests naturally. This review has three main objectives which were: to explain how agroforestry systems reduce pest problems through natural processes, identify the practical challenges that prevent more farmers from adopting these systems and propose evidence-based solutions to overcome these obstacles.

MEANING OF AGROFORESTRY. Understanding Ecological Buffering

Agroforestry is a land use system that deliberately integrates trees with crops and or livestock on the same piece of land to enhance productivity, sustainability and environmental health. It is a combination of agricultural and forestry practices that creates more diverse, resilient and resource efficient farming system.

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Ecological buffer refers to the capacity of an ecosystem to absorb disturbances such as pest outbreak, climate variability or soil degradation while at the same time maintain its essential function (Dollinger and Jose 2018). In an agroforestry systems, trees act as ecological buffers by improving soil fertility, moderating microclimate, supporting beneficial organisms and reducing the impact of environmental stressors on crops. Ecological buffer as a natural shock absorber help farmers handle pest pressures without collapsing into full-blown outbreaks. Agroforestry creates these buffers by making agricultural landscapes more complex and resilient.

TYPES OF AGROFORESTRY SYSTEMS

Several types of agroforestry arrangements can help with pest control:

- Alley cropping: Planting rows of trees with crops growing in the strips between them
- Silvopastoral systems: Combining trees with grazing animals
- Multistrata agroforests: Creating multiple layers of vegetation like a natural forest, with tall trees, medium-sized trees, shrubs, and ground crops
- Riparian buffers: Planting trees along streams and rivers
- Scattered tree parklands: Keeping widely spaced trees across crop fields, common in traditional African farming (Nair, 2012)

Research shows that multistrata systems with multiple vegetation layers typically work best for pest control because they provide the most complex habitat for beneficial creatures (Pumariño and Sileshi, 2017).

MECHANISMS OF PEST SUPPRESSION IN AGROFORESTRY SYSTEMS

Top-Down Regulation: Natural Enemy Conservation

Birds as Pest Controllers

Insect-eating birds provide valuable pest control services in agroforestry systems. Recent research in yerba mate agroforests found that birds reduced psyllid pest populations by 50% compared to treeless fields (Baggio *et al.*, 2025). The layered tree canopy gave birds places to perch, nest, and hunt for insects. Birds of prey like hawks also help indirectly by hunting pest birds such as starlings that damage fruit crops, they reduce crop losses (Monteagudo *et al.*, 2023)

Beneficial Insects

Agroforestry supports diverse communities of helpful insects including lady beetles, lacewings, and parasitic wasps. Recent research using advanced methods found that agroforestry fields have much higher functional diversity of these natural enemies than simple crop fields (Happe *et al.*, 2021). This means they have a wider variety of species with different hunting strategies and habitat needs, making pest control more reliable. The non-crop vegetation in agroforestry systems provides essential resources for these beneficial insects. When pest numbers are low in the main crop, natural enemies can survive on alternative prey or nectar from flowering plants in the tree rows. This ensures they are present and ready to respond when pest numbers increase (Wackers *et al.*, 2005).

Resource Dilution and Disruption of Host Location

The resource concentration hypothesis predicts that specialist herbivores more efficiently locate and exploit concentrated host plant resources in monocultures compared to diverse systems. Agroforestry systems disrupt pest host location through visual and olfactory interference, resource dilution, and stimulo-deterrent diversionary effects. Wide spacing of host plants within intercropping schemes increases search time for herbivores, while non-host vegetation emits volatile organic compounds that may confuse host-seeking behavior (Ratnadass *et al.*, 2012).

Moderating Microclimate

Trees modify the growing environment beneath them. They reduce temperature extremes, increase humidity, and block wind. These changes can slow pest development or make conditions less favorable for them to reproduce (Pumariño and Sileshi, 2017). However, these effects vary by location and pest type some pests might actually benefit from the moderated conditions.

Improving Soil Health and Plant Defenses

Agroforestry systems enhance soil organic matter, microbial diversity, and nutrient cycling, indirectly strengthening plant defense capacity. Regenerative agricultural practices incorporating trees demonstrate capacity to increase soil organic matter by 1–2% annually, improving water retention and carbon sequestration while supporting belowground biodiversity that contributes to pest suppression (Lal, 2020). Healthy soils foster mycorrhizal associations and plant growth-promoting rhizobacteria that induce systemic resistance in crop plants against herbivores and pathogens

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Complex Food Webs

Modern understanding emphasizes that pest control emerges from complex interactions among many species, not just simple predator-prey relationships. Agroforestry creates the structural complexity needed for these complex food webs. However, complexity can sometimes cause problems. When many predator species share the same prey, they may start eating each other a phenomenon called intraguild predation. This can actually reduce overall pest control (Snyder and Ives, 2001). Careful management, such as providing alternative prey, can minimize this problem.

EVIDENCE SYNTHESIS: EFFICACY ACROSS CROPPING SYSTEMS

Perennial vs. Annual Cropping Systems

Research clearly shows that agroforestry works much better for long-term crops than for annual crops that are planted and harvested every year. A major analysis found consistent pest reduction in perennial crops like coffee, cocoa, and plantain, but inconsistent effects in annual crops like maize, rice, and beans (Pumariño and Sileshi, 2017). This difference likely occurs because perennial systems provide stable habitat where natural enemy communities can establish and thrive over time. Annual cropping involves regular soil disturbance and harvest that disrupts these communities. Recent research confirms this pattern. In yerba mate—a perennial crop—agroforestry reduced pest populations by half. Meanwhile, annual crop systems show variable results depending on the specific pest (Baggio *et al.*, 2025).

System-Specific Pest Responses

Not all pests respond the same way to agroforestry. Research shows that Meta-analytic evidence indicates that root flies (Diptera: Anthomyiidae) experience 38% reduction, pollen beetles (*Brassicogethes* spp.) 57% reduction, and wheat stem sawfly (*Cephus pygmaeus*) 37% reduction in agroforestry compared to arable systems (Happe *et al.*, 2021). Conversely, slug abundance was 39% higher in agroforestry alleys, representing a trade-off requiring management attention. These taxon-dependent responses highlight the necessity of pest-specific considerations in agroforestry design rather than assuming universal pest suppression. The slugs represent an important trade-off. The permanent ground cover and moist conditions in agroforestry systems benefit slugs, which can become problematic pests of seedlings and young plants (Happe *et al.*, 2021). This highlights that agroforestry is not a universal solution and requires pest-specific management.

CHALLENGES CONSTRAINING IMPLEMENTATION AND EFFICACY

Despite the benefits, many obstacles prevent widespread adoption of agroforestry for pest control. These challenges operate at different levels from the farm itself to broader economic and policy environments (Bhandari *et al.*, 2025).

Tree-Crop Competition

The most immediate biophysical challenge involves resource competition between trees and crops. Competition for light, water, and nutrients can reduce crop yields, particularly in simultaneous agroforestry systems where trees and crops occupy the same temporal and spatial niches. In temperate alley cropping systems, competition for water has been identified as the primary determinant of productivity limitation, with belowground competition often exceeding aboveground shading effects (Jose *et al.*, 2000). Trees with extensive root systems may deplete soil moisture in crop alleys, while dense canopies reduce photosynthetically active radiation reaching understory crops. Additional trade-offs include potential for trees to host pests or diseases affecting crops. Coffee shade trees may serve as alternative hosts for the black twig borer (*Xylosandrus compactus*), while birds roosting in trees can damage grain crops and create food safety concerns through faecal contamination (Friday and Fownes, 2002). The rapid regeneration of trees may displace food crops if management lapses, and food crops may be damaged during tree harvesting operations.

Knowledge and Technical Capacity Gaps

Significant knowledge gaps persist regarding appropriate species combinations, spatial configurations, and management protocols for specific agro-ecological contexts. Farmers frequently lack technical knowledge regarding tree-crop interactions, pruning techniques, and pest monitoring in complex systems (Bhandari *et al.*, 2025). Extension services often inadequately address agroforestry-specific requirements, with weak training approaches for smallholder farmers limiting adoption (Food Forward NDCs, 2024). The lag between investment and return creates particular challenges; trees typically require several years to mature and deliver pest suppression benefits, during which farmers must maintain management inputs without receiving corresponding ecosystem services (Nair, 2012). This temporal mismatch between costs and benefits discourages adoption among resource-constrained farmers.

Economic and Market Barriers

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High upfront investment costs for seedlings, establishment, and maintenance exceed immediate returns for many farmers, creating negative cash flows during establishment phases (Wambugu *et al.*, 2021). Limited access to credit and financial resources prevents smallholders from financing long-term investments, while weak markets for agroforestry products (timber, fruits, nuts) reduce economic incentives (Place *et al.*, 2013). Price fluctuations and inadequate infrastructure for processing and selling diversified products further constrain economic viability

Land Tenure and Policy Constraints

Insecure land and tree tenure systems discourage long-term investments in perennial vegetation (Ajayi *et al.*, 2011). Where farmers lack clear ownership rights or face uncertain land access, planting trees represents risky behavior with potentially unrecoverable investments. Policy frameworks frequently fail to provide adequate incentives, with complex regulations and lack of specific agroforestry policies creating institutional barriers (Bhandari *et al.*, 2025). Gendered access to resources and decision-making authority further constrains adoption, with women facing particular barriers in many agricultural contexts (Kiptot and Franzel, 2012).

Contextual Variability and Unpredictability

The efficacy of agroforestry for pest suppression demonstrates high context dependency. Effects vary with crop type, pest species, tree species composition, climate, soil conditions, and landscape context. This variability complicates the development of universal recommendations and requires site-specific adaptation that demands sophisticated ecological knowledge. Additionally, climate change introduces novel uncertainties, with extreme weather events potentially disrupting established pest-natural enemy relationships in agroforestry systems.

Strategic Species Selection and System Design

Appropriate species selection represents the foundation for minimizing competition and maximizing pest suppression. Selecting tree species with compact crowns, delayed leaf emergence, or deciduous phenology can reduce light competition while maintaining beneficial habitat structure (Friday, 2025). Deep-rooted species minimize belowground competition for water and nutrients with shallow-rooted crops, while nitrogen-fixing species can enhance soil fertility if properly managed (Radovich *et al.*, 2015).

Spatial design principles include orienting tree rows east-west to maximize alley illumination,

maintaining adequate alley widths to balance crop productivity and tree benefits, and establishing buffer zones between trees and crops to reduce edge competition. Root pruning through subsoil ripping at tree canopy edges can significantly decrease root intrusion into crop zones, maintaining commercial yields even as shade levels increase (Center for Agroforestry, 2024).

Competition between Trees and Crops

The most immediate practical problem is that trees and crops compete for the same resources: sunlight, water, and nutrients. In alley cropping systems, trees can reduce crop yields, especially when they are young and growing rapidly. Research shows that water competition is often the main problem, with tree roots accessing water from crop zones (Jose *et al.*, 2000). Trees can also create problems by hosting pests that attack crops, or by providing perches for birds that eat fruits or grains. If not properly managed, trees may eventually shade out food crops entirely. These trade-offs require careful management and technical knowledge that many farmers lack.

Variable Results

Agroforestry doesn't work the same way everywhere. Results vary dramatically depending on crop type, local climate, soil conditions, which tree species are used, and the surrounding landscape. This variability makes it difficult to create universal recommendations and requires farmers to adapt general principles to their specific situations. Climate change adds further uncertainty, as changing weather patterns may disrupt established pest-natural enemy relationships.

SOLUTIONS AND STRATEGIC INTERVENTIONS

Addressing the challenges constraining agroforestry implementation requires integrated solutions spanning technical, economic, and policy domains.

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Adaptive Management Protocols

Implementing adaptive management based on regular monitoring of pest populations, natural enemy activity, and crop-tree competitive interactions enables timely interventions. Canopy management through pruning maintains semi-open crown conditions that permit sufficient light penetration while preserving habitat structure for natural enemies. Pruning strategies must balance timber quality objectives with pest suppression requirements, recognizing that excessive pruning (>40% foliage removal) significantly reduces tree growth. Integrated protocols should incorporate phenological synchronization—matching tree leaf emergence with crop growth stages to optimize resource availability while minimizing competition. For example, selecting tree species that break dormancy late benefits early-maturing crops such as winter wheat, while species with early leaf senescence accommodate late-harvested crops (Center for Agroforestry, 2024).

Economic and Policy Interventions

Financial mechanisms addressing the temporal mismatch between investment and returns include: payment for ecosystem services (PES) schemes compensating farmers for pest suppression and other ecological benefits; low-interest loans supporting establishment costs; and interim income sources during tree maturation periods (Ajayi *et al.*, 2011). Linking project costs to government subsidy programs, dedicated credit lines, and blended finance models can reduce financial barriers (Food Forward NDCs, 2024). Policy solutions require secure land and tree tenure systems, specific agroforestry policies with clear implementation guidelines, and coordination across agricultural, forestry, and environmental sectors. Strengthening extension services with agroforestry-specific expertise and establishing demonstration farms facilitates knowledge transfer (Bhandari *et al.*, 2025). Gender-sensitive programming ensuring women's access to resources, training, and decision-making authority addresses social equity constraints.

Participatory Research and Farmer Networks

Co-design approaches involving farmers, researchers, and extension agents in developing context-specific agroforestry configurations enhance adoption and adaptive capacity. Farmer field schools and peer-to-peer learning networks facilitate experiential knowledge exchange regarding pest management in complex systems. Participatory variety selection for tree species with optimal combinations of growth characteristics, pest suppression potential, and market value ensures locally appropriate solutions.

Landscape-Scale Coordination

While field-scale agroforestry provides significant benefits, landscape-scale coordination enhances pest suppression through source-sink dynamics and metapopulation processes. Networks of agroforestry patches connected through hedgerows and riparian buffers create habitat corridors facilitating natural enemy movement across agricultural landscapes. Such coordination requires collective action mechanisms and landscape-level planning integrating multiple farm units.

Future Research Directions

Several critical research gaps warrant attention. First, long-term longitudinal studies tracking pest-natural enemy dynamics through agroforestry establishment and maturation phases are necessary to understand temporal dynamics. Second, economic analyses incorporating ecosystem service valuations, including pest suppression benefits, must inform cost-benefit assessments. Third, climate change impacts on agroforestry-pest interactions require investigation, including extreme weather resilience and shifting pest ranges. Fourth, social science research addressing adoption barriers, particularly gendered dimensions and tenure security, must accompany biophysical studies. Finally, participatory action research integrating indigenous and local knowledge with scientific approaches can enhance context-specific design principles.

Conclusion

Agroforestry systems represent multifunctional ecological infrastructure capable of buffering pest outbreaks in organic farming through multiple complementary mechanisms. The evidence base demonstrates consistent enhancement of natural enemy abundance and significant suppression of specific pest taxa, particularly in perennial cropping systems and for disturbance-sensitive specialist herbivores. However, realizing these benefits requires addressing substantial challenges including tree-

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crop competition, knowledge gaps, economic barriers, and tenure constraints.

Solutions emphasizing strategic species selection, adaptive management, economic incentives, and policy support can overcome these constraints. The transition from monoculture to agroforestry systems represents not merely a technical change but a fundamental shift toward ecological intensification that recognizes agriculture as embedded within broader ecosystem processes. As organic farming expands to meet sustainability imperatives, agroforestry offers a pathway to pest resilience that aligns productivity with ecological integrity. Future success depends on integrated approaches combining biophysical optimization with social and institutional innovations that support farmer adoption and long-term stewardship of these complex, beneficial systems

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21

SPECIAL ISSUE



MAY, 2026



ISSN 2315-8567



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