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Integration of entomology and agronomy for sustainable crop production: A review

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Abstract

Entomology and agronomy have historically developed as separate disciplines, yet insect activity and crop management decisions are inseparably linked in the field. This review synthesizes recent literature (2018-2026) on how the two disciplines converge to support sustainable crop production, with an emphasis on cultural practices (crop rotation, intercropping, trap cropping), biological and ecosystem-service considerations (natural enemies, pollinators), and precision-technology tools (remote sensing, Internet of Things sensing, artificial intelligence-assisted monitoring) operating within an Integrated Pest Management (IPM) framework. A structured literature search across major databases identified 84 studies meeting inclusion criteria for qualitative synthesis. Evidence indicates that diversified cropping systems consistently increase beneficial-arthropod abundance and richness while suppressing pest populations, that IPM adoption reduces reliance on broad-spectrum pesticides without compromising yield, and that digital monitoring tools are narrowing the gap between entomological detection and agronomic decision-making. Climate change is identified as a cross-cutting pressure that is altering pest distribution, pest-crop synchrony, and pollinator availability, reinforcing the need for interdisciplinary, adaptive management. The review concludes that durable gains in sustainability depend on institutionalizing entomological data streams within routine agronomic decision cycles rather than treating pest management as a downstream, reactive activity.

Keywords: Integrated pest management; agroecology; crop rotation; intercropping; precision agriculture; beneficial insects; sustainable agriculture; climate change

1. Introduction

Global food systems face a dual mandate: agricultural output must expand to meet the demands of a growing population while simultaneously reducing the environmental footprint of production. Insect pests alone are estimated to threaten a substantial share of the world's major grain harvests, and this threat is projected to intensify as warming temperatures increase insect metabolic and reproductive rates. At the same time, insects deliver indispensable ecosystem services an estimated majority of flowering crop species depend to some degree on insect pollination, and natural enemy communities suppress pest populations that would otherwise require chemical intervention.

Agronomy, the science of crop production and soil management, and entomology, the study of insects, have traditionally been taught, researched, and practiced as distinct fields. In practice, however, nearly every agronomic decision what to plant, when to plant it, how to arrange it in the field, how to fertilize and irrigate it, and when to harvest it reshapes the insect community that interacts with that crop. Conversely, entomological knowledge of pest life cycles, natural-enemy requirements, and economic injury levels is only actionable when it is translated into field-level agronomic decisions. This review examines the current evidence base for that integration, organized around cultural practices, IPM as an operational framework, ecosystem services delivered by beneficial insects, precision and digital monitoring technologies, and the cross-cutting influence of climate change.

2. Materials and Methods

This review followed a structured, PRISMA-informed literature search and synthesis procedure rather than a formal systematic review with meta-analytic pooling, given the breadth of subtopics involved.

2.1 Search strategy. Peer-reviewed literature was retrieved from Scopus, Web of Science, PubMed/PMC, CAB Abstracts, and Google Scholar. Boolean search strings combined terms from three thematic clusters: (i) discipline terms (“entomology,” “agronomy,” “crop protection”); (ii) practice terms (“integrated pest management,” “crop rotation,” “intercropping,” “biological control,” “pollinator,” “precision agriculture,” “remote sensing,” “artificial intelligence”); and (iii) outcome terms (“sustainable,” “yield,” “pesticide reduction,” “climate change”).

2.2 Eligibility criteria. Sources were limited to English-

language, peer-reviewed journal articles, systematic reviews, and reputable institutional/agency reports published between 2015 and 2026, with priority given to publications from 2023 onward for technology-related subsections. Opinion pieces without empirical or synthesized data, duplicate reports of the same dataset, and non-agricultural entomology studies were excluded.

2.3 Selection and synthesis. Titles and abstracts were screened for thematic relevance, followed by full-text assessment of shortlisted records. Data extracted included agronomic practice or technology, entomological outcome measured, direction and magnitude of effect (where quantified), and study context. Findings were synthesized narratively and organized thematically rather than by publication chronology, consistent with standard review-paper methodology in agricultural science.

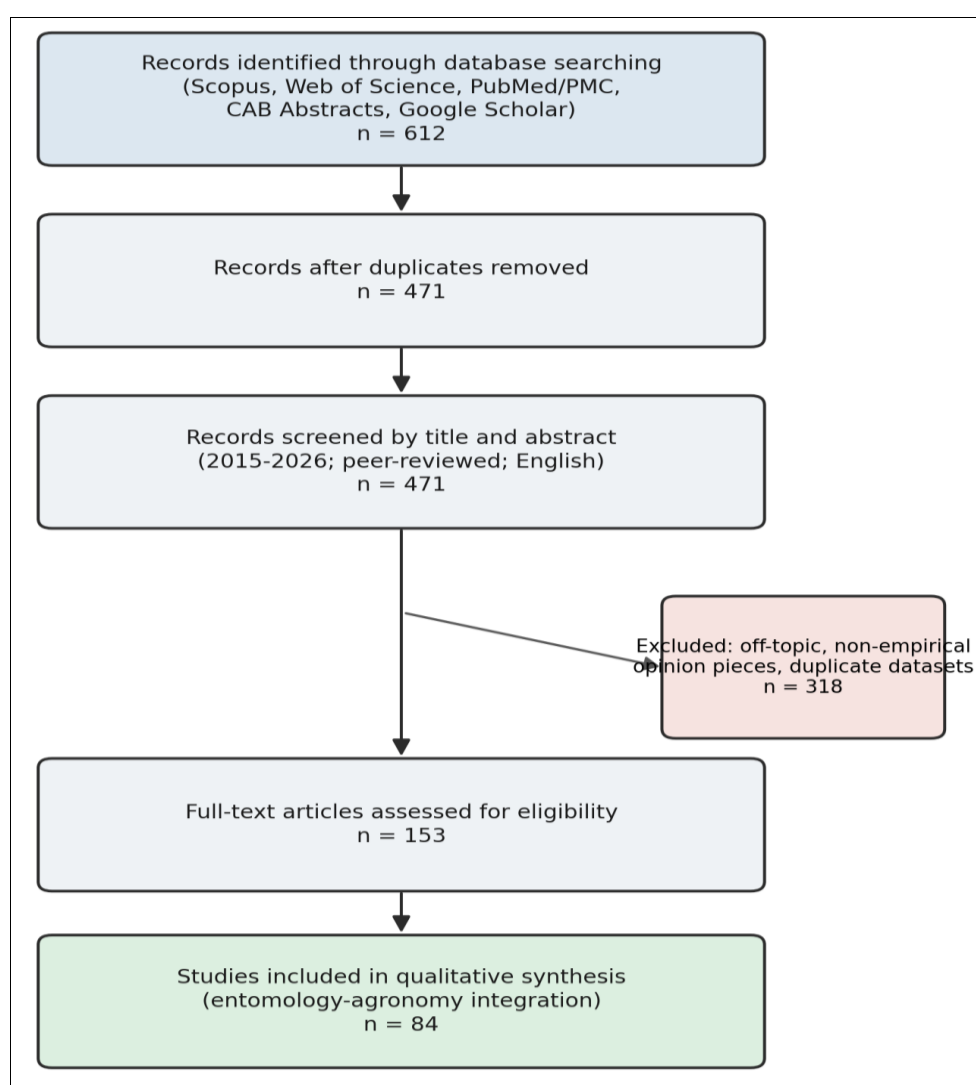


Fig 1: Literature search and study selection process used for this review.

3. Conceptual Framework for Entomology-Agronomy Integration

Figure 2 presents the conceptual framework guiding this review. Entomological knowledge (pest biology, natural-enemy ecology, pollinator science) and agronomic practice (crop management, soil and input scheduling, cultivar choice) converge in an

integrated crop-health management process. That process expresses itself through four operational channels: cultural and physical control, biological and ecosystem-service management, precision and digital monitoring tools, and threshold-based, climate-adapted decision support. Each of these channels is examined in the sections that follow.

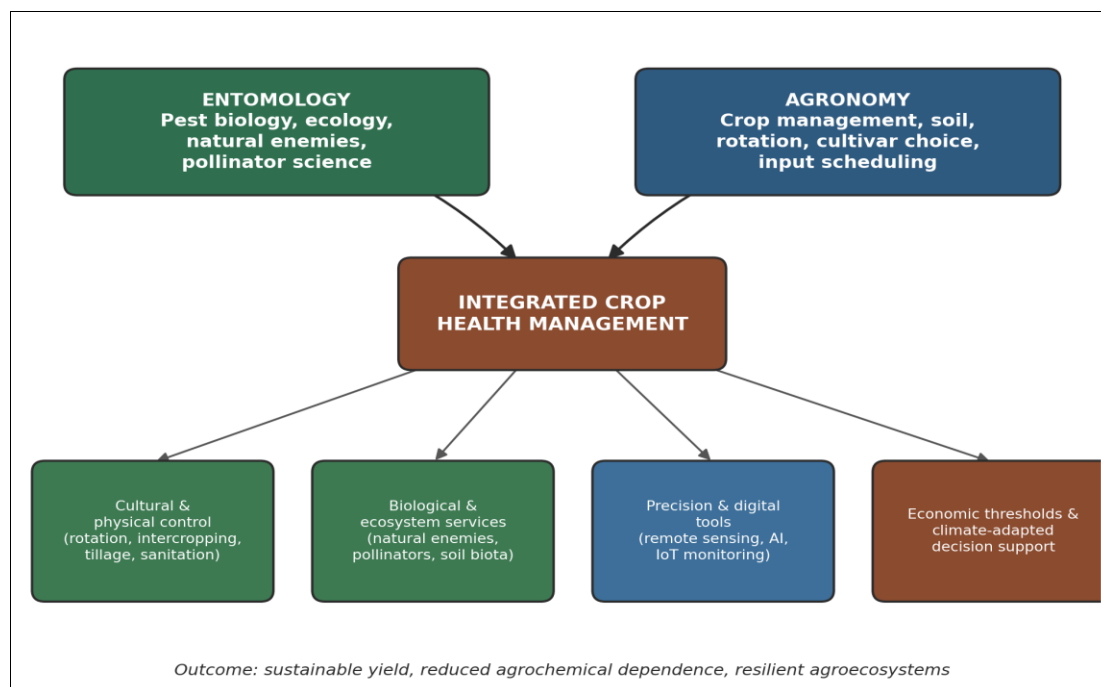


Fig 2: Conceptual framework linking entomological and agronomic knowledge domains to integrated crop-health outcomes.

4. Agronomic Practices and Their Entomological Effects

A recurring theme across the reviewed literature is that field-scale agronomic architecture what is planted, in what spatial arrangement, and in what sequence is itself a pest-management tool. Crop rotation interrupts the life cycle of pests with narrow host ranges and limited dispersal ability; soil-dwelling insects that emerge expecting a host crop instead encounter a non-host and fail to establish. Field studies in maize agroecosystems found that multi-year rotations reduced pest numbers relative to continuous monoculture, and that reduced chemical-input systems combined with rotation lowered pest counts further, although effects on natural-enemy populations were more variable and depended on insecticide and tillage regime.

Intercropping and strip-cropping systems increase structural and

chemical complexity in the field, which interferes with the host-location behavior of specialist pests and provides refuge and alternative prey for natural enemies. A meta-analysis spanning 63 studies across 18 countries found that intercropping increased beneficial-arthropod abundance and richness while reducing pest arthropod abundance and density (summarized in Figure 3 and Table 1); comparable reductions have been reported specifically for corn-soybean strip intercropping systems, alongside shifts in pest-community diversity indices. These benefits are not universal, however: intercropping tends to be more effective against specialist pests that rely on host-plant cues and can be neutral or even counterproductive for generalist pests, underscoring the need for practice selection matched to the target pest complex.

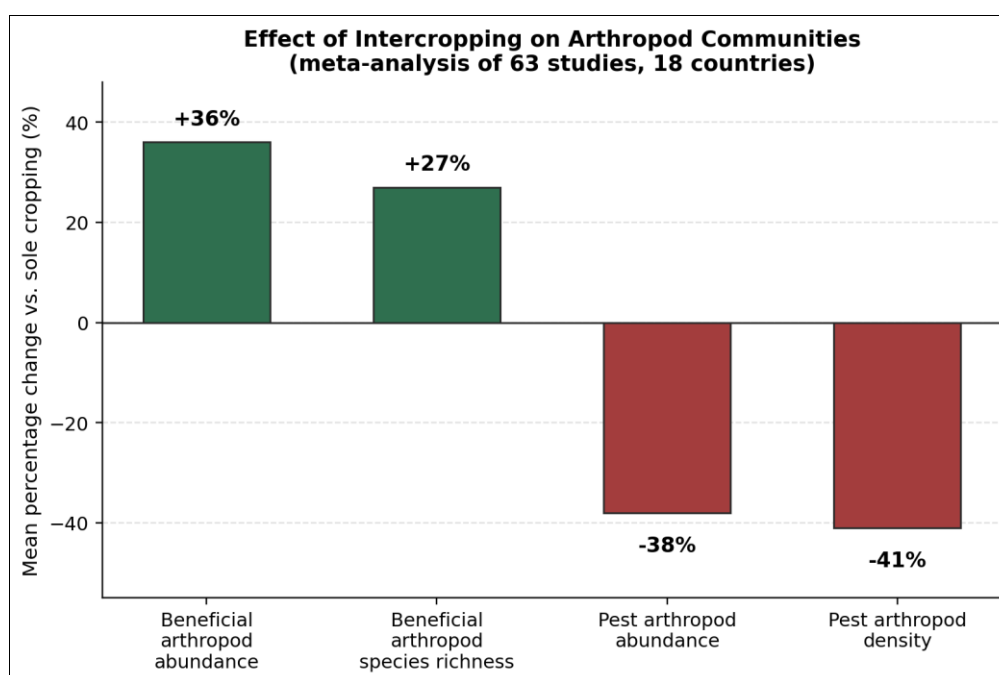


Fig 3: Reported change in arthropod communities under intercropping relative to sole cropping (meta-analysis of 63 studies).

Table 1 summarizes the principal agronomic practices identified in this review, the entomological mechanism through which

each operates, and the magnitude of effect reported in the literature

Table 1: Agronomic practices and their documented effects on insect pest and beneficial-arthropod communities

Agronomic practice	Primary entomological mechanism	Documented effect on insect community	Representative source
Crop rotation	Interrupts host-finding and larval survival; starves soil-dwelling stages awaiting a host	Multi-year rotations reduced soil and foliar pest numbers relative to continuous monoculture; reduced-input rotations lowered pest counts by ~38%	Studies on maize agroecosystems; rotation-pest suppression syntheses
Intercropping / strip cropping	Disrupts specialist host location via visual and olfactory (volatile organic compound) cues; increases natural-enemy habitat	Meta-analysis of 63 studies: +36% beneficial arthropod abundance, +27% richness, -38% pest abundance, -41% pest density	Corn-soybean strip intercropping trials; pulse-crop intercropping bibliometric review
Trap cropping	Provides a more attractive sacrificial host to divert oviposition/feeding away from the cash crop	Reduces chemical input requirement while conserving beneficial-insect communities	Cultural-practice reviews in organic systems
Tillage and sanitation	Physically destroys overwintering stages and removes crop residue harboring pests	Population-level effects reported as inconsistent and context-dependent across studies	Maize agroecosystem field trials
Legume-based rotation / cover cropping	Alters soil nitrogen and organic matter, indirectly changing herbivore pressure and natural-enemy habitat	Soil organic carbon increased up to 18% under legume rotation versus monoculture, improving system resilience	Organic farming cultural-practice synthesis

5. Integrated Pest Management as the Operational Interface

Integrated Pest Management functions as the practical meeting point between entomological science and agronomic operations. IPM is not a single technique but a decision framework: preventive cultural practices reduce the likelihood of pest establishment; monitoring and economic-threshold determination decide whether intervention is warranted; biological, physical, and targeted chemical tools are then deployed in combination, informed by resistance-management principles; and outcomes are evaluated and fed back into the following season's agronomic planning. Recent critical reviews note that IPM's fundamental components cultural prevention, monitoring, threshold-based decisions, and blended control

tactics have remained conceptually stable even as the tools available for each component have advanced substantially, particularly in monitoring technology and biologically based control materials.

Policy and industry frameworks have converged on IPM as the reference standard for sustainable pest management; multinational stewardship initiatives explicitly position IPM, combining biological, cultural, physical, and chemical tools, as the cornerstone for reducing pesticide risk while maintaining productivity. Table 2 outlines the core pillars of IPM and identifies which discipline entomology, agronomy, or both jointly is primarily responsible for each pillar in practice.

Table 2: Core pillars of Integrated Pest Management and their disciplinary integration points.

IPM pillar	Agronomic-entomological integration point	Discipline emphasis
Prevention (cultural control)	Crop rotation, sanitation, resistant cultivar selection, and planting-date adjustment reduce pest establishment before it starts	Agronomy-led
Monitoring and identification	Field scouting, pheromone/light traps, and economic-threshold determination guide whether any intervention is warranted	Entomology-led
Biological control	Conservation, augmentation, or introduction of natural enemies; management practices (e.g., reduced tillage, flowering strips) that sustain these enemies	Entomology-led
Physical and mechanical control	Barriers, traps, and manual removal, often layered on top of standard field operations	Shared
Targeted chemical control	Pesticide selection, timing, and dose informed by threshold data and resistance-management rotation of modes of action	Shared
Evaluation and adaptive management	Season-end data feed back into rotation planning, cultivar choice, and monitoring intensity for subsequent seasons	Shared

6. Beneficial Insects and Ecosystem Services

Beneficial insects contribute to sustainable production through biological pest control, pollination, and soil-health processes such as organic matter decomposition. Habitat heterogeneity created by crop rotation and intercropping directly supports beneficial-insect diversity, which has led several reviews to advocate explicitly for Integrated Pest and Pollinator Management (IPPM) as a successor framework to conventional IPM one that optimizes pest suppression and pollination services jointly rather than treating them as separate management objectives.

Pollination services are economically significant and climate-sensitive. Research combining land-use and climate data across thousands of sites found that the interaction of agricultural land

use and recent climate change is associated with disproportionately large reductions in insect-pollinator abundance, with the greatest risk to pollination-dependent crops concentrated in tropical regions producing cocoa, mango, watermelon, and coffee. Complementary field research demonstrates that insect pollination benefits can remain robust even under water-stressed conditions, while insect herbivory and water stress interact to compound yield loss indicating that pollinator conservation and herbivore management should be pursued as a joint agronomic objective rather than in isolation.

7. Precision Agriculture and Digital Entomological Monitoring

The integration of entomology into precision agriculture has

historically lagged behind its integration into soil and water management, but this gap is narrowing rapidly. UAV- and satellite-based multispectral, hyperspectral, and thermal imaging can detect the physiological stress signatures associated with infestation before damage is visible to the eye, while entomological radar systems track the movement of migratory or high-flying pests such as invasive hornets and noctuid moths. IoT-connected smart traps and sensor networks provide continuous, automated pest counts that reduce dependence on manual field scouting.

Artificial intelligence, particularly convolutional neural networks and acoustic classification models, has enabled

automated pest identification with classification accuracies frequently exceeding 90% under controlled conditions, and AI-assisted pest management systems have been associated with pesticide-use reductions on the order of 20 to 40 percent in precision-agriculture contexts. A systematic review of 147 studies published between 2019 and 2025 documented a marked increase in the use of UAV and satellite platforms for pest and disease monitoring, though it also identified persistent barriers to field adoption, including data-integration complexity, cost of sensing infrastructure, and limited connectivity in smallholder farming contexts. Table 3 summarizes the principal technologies identified in this review and their entomological applications.

Table 3: Precision and digital technologies supporting entomological monitoring in crop production systems

Technology	Entomological application	Reported performance
UAV and satellite remote sensing (multispectral, hyperspectral, thermal)	Detects crop-stress signatures associated with infestation across large field areas	Increasing adoption 2019-2025; supports early, spatially targeted detection
Entomological radar and harmonic radar	Tracks flight height, speed, and movement of migratory or high-flying pest species	Used to monitor species such as hornets and migratory moths at altitudes up to ~500 m
IoT sensor networks and smart traps	Continuous, automated field-level pest counts feeding real-time decision support	Reduces manual scouting labor; supports targeted rather than blanket spraying
AI / machine learning (CNNs, acoustic classifiers)	Automated pest species identification and outbreak prediction from image or acoustic data	Classification accuracy often exceeds 90% under controlled conditions; associated with 20-40% pesticide-use reduction

8. Climate Change as a Cross-Cutting Pressure

Climate change intersects with nearly every theme addressed in this review. Because insect metabolism and reproduction are strongly temperature-dependent, warming is expected to expand the geographic range of many pest species, increase overwintering survival, add additional generations per season, and alter synchrony between pest emergence and host-plant availability. Modeling based on established temperature-population relationships projects that global yield losses of rice, maize, and wheat to insect pests will increase by 10 to 25 percent per degree of global mean surface warming, with the largest impacts concentrated in temperate grain-producing regions where both population growth and metabolic rates of pests are expected to rise together.

Climate change also threatens the natural-enemy and pollinator communities that underpin biological control and pollination services; some natural enemies may benefit from warming while others decline, adding unpredictability to pest-suppression outcomes. In East Africa, reviews describe how climate-driven shifts in flowering timing can desynchronize crops from their pollinators and can shift the population dynamics of economically important pests such as the coffee berry borer in ways that are not uniformly negative or positive. In response, recent frameworks such as Climate-Smart One-Health IPM have

proposed integrating ecological, environmental, and socio-economic factors explicitly linking climate adaptation, entomological monitoring, and agronomic decision-making within a single systems-thinking approach.

9. Quantitative Data on Crop Losses and Intervention Outcomes

To ground the qualitative synthesis above in measurable terms, this section consolidates the principal quantitative estimates identified across the reviewed literature, covering both the scale of the pest problem and the measured effect of entomology-informed agronomic interventions.

9.1 Scale of the problem. Global assessments place average crop production losses to pests at 10 to 28 percent across all major crops, with insects alone consuming an estimated 5 to 20 percent of major grain harvests in a typical year. A widely cited crop-loss synthesis estimated that, absent any crop protection, potential losses would range from roughly 50% in wheat to more than 80% in cotton; even with current protection practices in place, actual losses remain substantial across all five major food crops assessed in a subsequent global expert-elicitation study (Table 4, Figure 4).

Table 4: Estimated potential and actual global yield losses to pests and pathogens by major food crop

Crop	Potential loss without any crop protection	Actual loss with current protection practices	Notes
Wheat	~50%	21.5% (range 10.1-28.1%)	Insects alone consume an estimated 5-20% of major grain crops annually
Rice	Among the highest of cereals	30.0% (range 24.6-40.9%)	Highest estimated loss among the five major food crops assessed
Maize	Substantial, crop- and region-dependent	22.5% (range 19.5-41.1%)	Wide regional variability linked to pest complex and management intensity
Potato	Moderate relative to cereals	17.2% (range 8.1-21.0%)	Lowest actual loss among the five crops in the global assessment
Soybean	26-29%	21.4% (range 11.0-32.4%)	Losses concentrated in food-deficit, fast-population-growth regions
Cotton	>80% (highest of all crops assessed)	26-29%	Largest gap between potential and actual loss, reflecting intensive crop protection investment

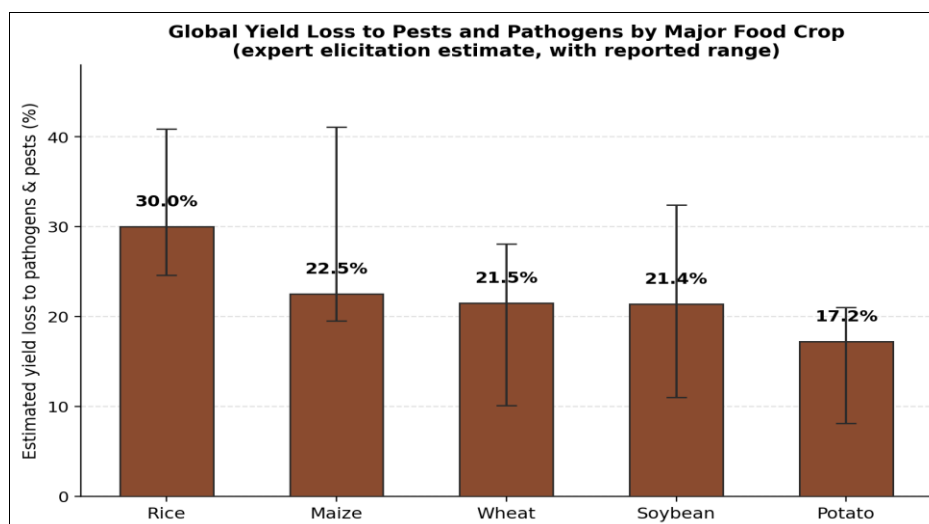


Fig 4: Global yield loss to pests and pathogens by major food crop, expert-elicitation estimate with reported uncertainty range

9.2 Measured effect of interventions. Table 5 draws together the principal quantified intervention outcomes discussed in Sections 4 through 8, spanning cultural practice, mechanization, digital monitoring, pollination services, and climate-driven risk. Read together, these figures indicate that the largest, most

consistently reported gains come from combining practices diversified cropping plus reduced chemical input, or precision monitoring plus targeted intervention rather than from any single tactic applied in isolation.

Table 5: Quantified outcomes of entomology-informed agronomic interventions reported across the reviewed literature

Intervention	Quantified outcome	Crop / system	Source basis
Multi-layer crop rotation + reduced chemical input	Pest numbers reduced; reduced-input systems lowered pest counts by 38% vs. conventional management	Maize agroecosystem	Field trial synthesis
Strip/row intercropping (meta-analysis)	+36% beneficial arthropod abundance; +27% richness; -38% pest abundance; -41% pest density	Cross-crop, 63 studies / 18 countries	Meta-analysis
Legume-inclusive rotation	Soil organic carbon increased up to 18% vs. monoculture	Cereal-legume rotation systems	Agronomy journal synthesis
Mechanized harvesting innovation	Yield losses at harvest reduced by up to 40%	Pea (<i>Pisum sativum</i>)	Cultivation-to-storage review
AI-assisted pest detection & decision support	Pesticide usage reduced by an estimated 20-40%; classification accuracy often >90% under controlled conditions	Cross-crop precision agriculture	AI-in-entomology review
Insect pollination service (independent of water stress)	Yield increased by 68% attributable to pollination, conserved regardless of water availability	Insect-pollinated field crop	Controlled field experiment
Climate warming effect on insect-driven crop loss	Global yield loss to insects projected to rise 10-25% per °C of warming (wheat, rice, maize)	Global grain production	Temperature-metabolism modeling
Global average pest burden (all crops)	10-28% of global crop production lost to pests on average	Global, all major crops	Global expert synthesis (Savary <i>et al.</i> , 2019)

9.3 Economic returns on entomology-informed investment. Beyond ecological and yield outcomes, a growing body of program-evaluation literature quantifies the direct economic return of integrating entomological monitoring and biologically based control into agronomic practice. Table 6 compiles benefit-cost findings from IPM and IPPM programs across Africa, Asia,

and North America. Reported benefit-cost ratios range from roughly 8:1 to 34:1 depending on crop system and region, and multi-country syntheses spanning dozens of projects report mean yield gains near 41% alongside pesticide-use reductions to about a third of baseline levels evidence that entomology-agronomy integration is financially, not only ecologically, advantageous.

Table 6: Economic outcomes of Integrated Pest Management and Integrated Pest and Pollinator Management adoption across regions and crop systems

Region / crop system	Study scope	Pesticide / cost outcome	Yield & return outcome
Kenya & Uganda – mango fruit-fly IPM and push-pull technology	Project investment and adoption data, 2007-2021	Reduced reliance on broad-spectrum insecticide applications	Combined net present value of US\$500 million; benefit-cost ratio ≈8:1; internal rate of return 21%
Kenya & Tanzania – avocado integrated pest and pollinator management (IPPM)	Ex-ante economic surplus modeling	Reduced pesticide load alongside conserved pollination service	Potential annual gain of US\$66 million (Kenya, BCR 13:1) and US\$1.4 million (Tanzania, BCR 34:1)
South/Southeast Asia – cotton IPM farmer field schools	Before/after comparison, IPM vs. non-IPM farms	Pesticide-spray cost reduced by ≈US\$112.83/ha (IPM) vs. US\$106.80/ha (non-IPM)	Yield increased by 649 kg/ha (IPM) vs. 505 kg/ha (non-IPM)
Bangladesh – eggplant, bitter melon, tomato IPM	Matched-comparison economic surplus analysis	Pesticide costs reduced by roughly US\$25/ha across vegetables studied	Internal rate of return up to 42% (eggplant), 39% (tomato)
Philippines – onion IPM	Contingent-valuation farmer survey, Central Luzon	Specific pesticide use reduced 25-65% depending on practice	Adoption ranged 36-94%; economic benefit ~231-305 pesos/person/season
United States – orchard and field-crop IPM programs	Multi-decade program review (California, Oregon)	IPM pest-control costs ~US\$160-200/acre vs. >US\$450/acre conventional	36% of 157 reviewed IPM projects achieved reduced pesticide use
Cross-regional – 85 IPM projects, 24 countries (Asia & Africa)	Multi-country program synthesis	Pesticide use reduced to ~30.7% of baseline; 30% of crop combinations reached zero pesticide use	Mean yield increase of 40.9% across projects
India – chilli IPM demonstration	Farm-level cost comparison	Pesticide/growth-booster cost ₹7,468 (IPM) vs. ₹13,836 (non-IPM), a reduction of ₹6,368/ha	Higher benefit-cost ratio and net returns versus non-IPM fields

9.4 Profiles of major globally significant pest species. The scale of loss summarized above is driven disproportionately by a relatively small number of highly polyphagous or migratory pest species. Table 7 profiles five of the most economically significant insect pests referenced in the reviewed literature,

spanning field-crop defoliators, sap-feeding vectors, migratory swarming species, and post-harvest storage pests, illustrating the taxonomic and ecological diversity that entomology-agronomy integration must address in practice.

Table 7: Profiles of major globally significant insect pest species and their documented economic impact

Pest species	Order / family	Principal host crops	Documented economic / yield impact
Fall armyworm (Spodoptera frugiperda)	Lepidoptera: Noctuidae	Maize, sorghum, rice, cotton, sugarcane; recorded on >350 host plants across 76 families	FAO estimates up to 17.7 million tonnes of maize lost annually across 12 African countries (US\$2.5-6.2 billion); average annual maize loss of 36% documented at household level; historic U.S. losses of US\$300-500 million/year
Desert locust (Schistocerca gregaria)	Orthoptera: Acrididae	Cereals, pasture, fodder, a wide range of standing crops	A swarm of 1 km ² (~80 million locusts) consumes food equivalent to the daily needs of 35,000 people; Indian wheat production estimated ~20% lower in upsurge years
Cotton bollworm (Helicoverpa armigera)	Lepidoptera: Noctuidae	Cotton, tomato, chickpea, pigeon pea, maize, sorghum, and other legume/vegetable crops	Insect and secondary infection can cause up to 80% loss in cotton fibre production; inflicts crop damage worth an estimated US\$1 billion annually in India alone
Brown planthopper (Nilaparvata lugens)	Hemiptera: Delphacidae	Rice (direct sap-feeding and oviposition damage; vectors rice viruses)	Recognized as one of the most economically damaging rice pests worldwide, causing stunting, "hopperburn," and yield loss across major rice-growing regions of Asia
Larger grain borer (Prostephanus truncatus)	Coleoptera: Bostrichidae	Stored maize and cassava (post-harvest pest)	Established in >50% of the African continent within a decade of introduction; contributes to continental crop-damage and pest-management costs estimated at US\$18.2-78.9 billion (1970-2020)

9.5 Biological control agents deployed against these pests. Complementing the pest profiles in Table 7, Table 8 summarizes representative predators, parasitoids, and entomopathogens used operationally within IPM programs. Recent syntheses emphasize that combining agent types for example, a predator, a parasitoid, and a microbial agent acting on different pest life stages

produces complementary, synergistic, or population-stabilizing interactions that outperform any single agent used alone, reinforcing the broader theme that integration, rather than substitution, drives the largest gains in sustainable pest suppression.

Table 8: Representative biological control agents used operationally within Integrated Pest Management programs.

Biological control agent	Agent type	Target pest(s)	Mode of action / documented role
Trichogramma spp. (T. pretiosum, T. achaeae)	Egg parasitoid (Hymenoptera: Trichogrammatidae)	Lepidopteran pests, including tomato leafminer (Tuta absoluta)	Deposits eggs inside host eggs, preventing larval hatch; among only four natural-enemy species currently in commercial-scale use against T. absoluta
Nesidiocoris tenuis / Macrolophus pygmaeus	Predatory mirid bugs (Hemiptera: Miridae)	Whiteflies, tomato leafminer eggs and larvae	Generalist predation on eggs, nymphs, and small larvae; used at larger scale in greenhouse tomato IPM, though can cause plant damage at high densities
Encarsia formosa / Encarsia eremicus	Parasitoid wasps (Hymenoptera: Aphelinidae)	Whitefly (Bemisia tabaci) nymphs	Lays eggs inside whitefly nymphs, weakening and killing the host; commonly combined with predators and entomopathogens for layered control
Trissolcus japonicus (samurai wasp)	Egg parasitoid (Hymenoptera: Scelionidae)	Brown marmorated stink bug (Halyomorpha halys)	Naturally dispersing biological control agent first detected in the U.S. Pacific Northwest in 2015-2016, now established as a regional control factor
Rhynocoris fuscipes (reduviid assassin bug)	Generalist predator (Hemiptera: Reduviidae)	Fall armyworm, common armyworm, oriental armyworm, aphids, planthoppers	Broad prey range with demonstrated predation capacity on multiple economically important noctuid pests across Africa, Asia, and the Americas
Entomopathogens (e.g., Beauveria, Metarhizium, Bacillus thuringiensis)	Microbial biological control agents (fungi, bacteria)	Whiteflies, lepidopteran larvae, and other soft-bodied pests	Infects and kills pests through disease pathways; high target specificity, but field efficacy depends on temperature, humidity, and UV exposure, favoring rotation with other tactics

9.6 Insecticide resistance as a constraint on chemical control. The long-term reliability of chemical control one of the tactics blended within IPM (Table 2) is increasingly constrained by evolved resistance. Table 9 summarizes documented resistance data for several economically important pest species, illustrating

both the scale of the problem (hundreds of independently logged resistance cases for globally distributed pests) and its dynamic nature (resistance ratios that can increase by an order of magnitude within two to three growing seasons).

Table 9: Documented insecticide resistance status in selected major agricultural pest species

Pest species	Insecticide class affected	Documented resistance status	Region
Two-spotted spider mite (Tetranychus urticae)	Multiple chemical classes	558 reported resistance cases logged in the Arthropod Pesticide Resistance Database	Global
Silverleaf whitefly (Bemisia tabaci)	Neonicotinoids and multiple other classes	898 reported resistance cases; field populations show near-total loss of imidacloprid efficacy	Global / China
Striped rice stem borer (Chilo suppressalis)	Diamides (chlorantraniliprole) and legacy classes	Resistance evolved to nearly all previously available insecticide classes; chlorantraniliprole resistance now emerging and quantitatively tracked	China
Cotton aphid (Aphis gossypii)	Afidopyropen (microbial secondary metabolite-derived)	Resistance ratio rose from 0.03-3.97 (2019) to 3.47-95.06 (2021) across field populations	China

9.7 Global and regional pesticide use context. Agronomic reliance on chemical inputs varies substantially by region and has grown in absolute terms even as IPM adoption has expanded (Table 10). Global agricultural pesticide use reached

approximately 3.69-3.73 million tonnes of active ingredient in 2022-2023, roughly double the 1990 level, with application intensity highest in the Americas and lowest, per hectare, in Europe.

Table 10: Regional agricultural pesticide application rates and use trends

Region	Application rate (kg/ha, 2022)	Notable trend	Source year
Americas	~5.11 kg/ha	Highest regional application rate; region accounts for more than half of global pesticide use	2021-2022
Oceania	~1.98 kg/ha	Use nearly tripled since 1990, reaching ~67 kt/year by 2021-2022; herbicide share rising	2021-2022
Europe	~1.66 kg/ha	Below world average; imported ~1.27 Mt/year on average, 1990-2022	2022
World average	~2.37 kg/ha	Global total use 3.69 Mt (2022) and 3.73 Mt (2023), roughly double the 1990 level	2022-2023

Table 11 breaks this total down by pesticide category. Herbicides dominate global use by volume, while insecticides the category most directly shaped by entomological decision-making represent a smaller but still substantial share, with

regional trends (e.g., a declining insecticide share in Oceania) suggesting that cultural and biological tactics are beginning to displace some insecticide use even as total pesticide volumes rise.

Table 11: Global agricultural pesticide use by category, 2022, with longer-term trend context

Pesticide category	Global volume (2022)	Share of total use	Trend
Herbicides	1.94 million tonnes	Largest single category (>50%)	Rising share in most regions, including Oceania (67% → 71%, 1990s-2013/22)
Insecticides	<1 million tonnes	Second-largest category	Declining share in some regions (e.g., Oceania: 21% → 19%)
Fungicides / bactericides	<1 million tonnes	Minor but stable category	Relatively stable share (e.g., 9% → 8% in Oceania)
All categories combined	3.69-3.73 million tonnes (2022-2023)	100%	Increased 14% in the past decade and has doubled globally since 1990

9.8 Economic value of insect pollination by crop category. Complementing the pest-focused data above, Table 12 quantifies the positive economic contribution of insect pollinators discussed qualitatively in Section 6. Vegetables and fruits

represent the largest absolute pollination-service values, while stimulant crops such as coffee and cocoa show the highest proportional dependence on insect pollination, making them the crop category most economically exposed to pollinator decline.

Table 12: Estimated global economic value of insect pollination by major crop category.

Crop category	Estimated annual pollination value	Vulnerability ratio*	Notes
Vegetables	~€50 billion	Moderate-high	Among the two largest value categories globally
Fruits	~€50 billion	~23%	Second of the two largest value categories
Edible oilseed crops	~€39 billion	Moderate	Third-largest pollination-dependent category
Stimulants (coffee, cocoa)	Smaller absolute value, highest sensitivity	~39% (highest of all categories)	Most vulnerable category to pollinator decline on a proportional basis
Nuts	Moderate absolute value	~31%	Second-highest vulnerability ratio
Global total (all pollinator-dependent crops)	Estimates range €153 billion (2005) to US\$235-800 billion (recent estimates)	9.5% of world agricultural food production value (2005 baseline)	Range reflects differing methodologies and price years across studies

10. Challenges and Knowledge Gaps

Despite convergence in principle, several structural challenges limit the integration of entomology and agronomy in practice. First, disciplinary training and extension services often remain siloed, so agronomic recommendations and pest-management recommendations reach farmers through separate channels rather than as a unified package. Second, cultural practices such as intercropping and trap cropping are information-intensive: their effectiveness depends on matching the practice to the specific pest-crop-natural enemy complex present in a given field, and a practice that performs well in one context may be ineffective or even counterproductive in another. Third, precision-technology adoption is uneven, with cost, data-integration complexity, and rural connectivity limiting uptake among smallholder producers, who represent a substantial share

of global crop production. Finally, climate change introduces a moving baseline that complicates the transfer of historical pest-management knowledge to future growing seasons, reinforcing the need for adaptive, continuously updated decision-support systems rather than static recommendations.

11. Future Directions

Building on the evidence synthesized here, three priorities emerge for future research and practice. First, breeding and cropping-system design should be evaluated jointly for agronomic performance and entomological outcomes, rather than sequentially, so that pest-suppressive or pollinator-supportive traits are treated as core agronomic criteria rather than afterthoughts. Second, investment in accessible, low-cost digital monitoring infrastructure is needed to extend the benefits

of AI-assisted pest detection beyond well-resourced production systems. Third, extension and training programs should be restructured around integrated crop-health curricula that combine entomological and agronomic content, supporting the kind of interdisciplinary, participatory implementation that recent IPM and IPPM frameworks call for.

12. Conclusion

The evidence reviewed here indicates that entomology and agronomy are most effective as complementary, rather than sequential, disciplines within sustainable crop production. Cultural practices rooted in agronomic decision-making rotation, intercropping, and trap cropping demonstrably reshape pest and beneficial-insect communities; IPM provides the operational framework through which entomological monitoring and agronomic action are integrated; beneficial insects deliver pollination and biological-control services that are themselves sensitive to agronomic and climatic conditions; and emerging digital technologies are progressively closing the gap between pest detection and field-level decision-making. Realizing the full sustainability potential of this integration will depend less on further disciplinary specialization and more on institutional, educational, and technological structures that treat entomological data as a routine input to agronomic planning, rather than as a reactive response to crop damage already incurred.

References

1. Agriculture Institute. Practical applications of cost benefit analysis in agricultural projects [Internet]. 2026 [cited 2026 Jul 24]. Available from: <https://agriculture.institute/farm-cost-mgt/cost-benefit-analysis-agriculture-projects/>
2. Bayer Global. Economic value of pollinators [Internet]. 2025 [cited 2026 Jul 24]. Available from: <https://www.bayer.com/en/agriculture/article/economic-value-pollinators>
3. Evolving resistance patterns in *Tetranychus urticae* and *Bemisia tabaci* in Greece [Internet]. bioRxiv; 2025 [cited 2026 Jul 24]. Available from: <https://www.biorxiv.org/content/10.1101/2025.05.31.656940.full.pdf>
4. Food and Agriculture Organization of the United Nations. Pesticides use, pesticides trade and pesticides indicators [Internet]. Rome: FAO; 2024 [cited 2026 Jul 24]. Available from: <https://openknowledge.fao.org/server/api/core/bitstreams/78705276-3455-4c70-ac77-3082095f83b3/content>
5. Food and Agriculture Organization of the United Nations. Pesticides use and trade, 1990-2023 [Internet]. Rome: FAO; 2025 [cited 2026 Jul 24]. Available from: <https://www.fao.org/statistics/highlights-archive/highlights-detail/pesticides-use-and-trade-1990-2023/en>
6. Gallai N, Salles JM, Settele J, Vaissière BE. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*. 2009;68(3):810-821.
7. Species identification, insecticide resistance and TYLCV detection of *Bemisia tabaci* in Kashgar, Xinjiang. *PubMed Central*. 2025; PMC12842364. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC12842364/>
8. The evolution of pesticide resistance: A data-driven case study of chlorantraniliprole resistance in *Chilo suppressalis* and other lepidopteran pests in China. *PubMed Central*. 2025; PMC12229950. Available from: <https://pmc.ncbi.nlm.nih.gov/articles/PMC12229950/>
9. Status of the resistance of *Aphis gossypii* Glover, 1877 (Hemiptera: Aphididae) to afidopyropen originating from microbial secondary metabolites in China. *PubMed Central*. 2022; PMC9695873. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9695873/>
10. CropLife International. Sustainable Pesticide Management Framework (SPMF) 2026 Annual Report Summary [Internet]. 2026 [cited 2026 Jul 24]. Available from: <https://croplife.org/sustainable-pesticide-management-framework-spmf/>
11. Deutsch CA, Tewksbury JJ, Tigchelaar M, Battisti DS, Merrill SC, Huey RB, Naylor RL. Increase in crop losses to insect pests in a warming climate. *Science*. 2018;361(6405):916-919.
12. Food and Agriculture Organization of the United Nations. About FAO's work on plant production and protection [Internet]. Rome: FAO; 2025 [cited 2026 Jul 24]. Available from: <https://www.fao.org/plant-production-protection/about/en>
13. Food and Agriculture Organization of the United Nations. Global pests affecting crops, forestry and ecosystems [Internet]. Rome: FAO; 2024 [cited 2026 Jul 24]. Available from: <https://openknowledge.fao.org/server/api/core/bitstreams/fe50815a-fe81-467f-bc06-e15d68dd4e04/content/src/html/global-pests-affecting-crops-forestry-and-ecosystems.html>
14. International Plant Protection Convention. About Fall Armyworm [Internet]. IPPC; 2024 [cited 2026 Jul 24]. Available from: <https://www.ippc.int/en/the-global-action-for-fall-armyworm-control/about-fall-armyworm/>
15. Oerke EC. Crop losses to pests. *Journal of Agricultural Science*. 2006;144(1):31-43.
16. The fall armyworm and larger grain borer pest invasions in Africa: Drivers, impacts and implications for food systems. *PubMed Central*. 2024; PMC10968395. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10968395/>
17. Integrative omics strategies for understanding and combating brown planthopper virulence in rice production: A review. *PubMed Central*. 2024; PMC11507613. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11507613/>
18. Desert locust outbreaks: Ecological and economic impacts and management strategies. *Frontiers in Zoology*. 2026. Available from: <https://link.springer.com/article/10.1186/s12983-026-00613-6>
19. University of Chicago Institute for Climate and Sustainable Growth. Valuing disaster prevention: Desert locust monitoring and control [Internet]. 2026 [cited 2026 Jul 24]. Available from: <https://climate.uchicago.edu/insights/valuing-disaster-prevention-desert-locust-monitoring-and-control/>
20. The economic, social, and environmental impact of ecologically centered integrated pest management practices in East Africa. *ScienceDirect*. 2024. Available from: <https://www.sciencedirect.com/science/article/pii/S0301479724032274>
21. Cuyno LCM, Norton GW, Rola A. Economic analysis of environmental benefits of integrated pest management: A Philippine case study. *Agricultural Economics*. 2001;25(2-3):227-233.
22. Synergies of integrated pest and pollinator management in

- avocado farming in East Africa: An ex-ante economic analysis. PubMed Central. 2022; PMC9312383. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9312383/>
23. Savary S, Willocquet L, Pethybridge SJ, Esker P, McRoberts N, Nelson A. The global burden of pathogens and pests on major food crops. *Nature Ecology & Evolution*. 2019;3:430-439.
 24. Zhang H, Sun H, Tang Z, Wang G. Integrated agronomy of pea (*Pisum sativum* L.): A review on cultivation, harvesting, and storage for sustainable agriculture. *Frontiers in Plant Science*. 2025; PMC12541591. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC12541591/>
 25. Harnessing natural enemies for sustainable management of *Bemisia tabaci*: A review of the role of predators, parasitoids and entomopathogens. *Frontiers in Agronomy*. 2025. Available from: <https://www.frontiersin.org/journals/agronomy/articles/10.3389/fagro.2025.1684672/full>
 26. Multifunctional roles of intercropping in the management of insect pests affecting pulse crops: A comprehensive bibliometric analysis. *Frontiers in Sustainable Food Systems*. 2025. Available from: <https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2025.1599254/full>
 27. International Atomic Energy Agency. Insect pest control: Biological control [Internet]. IAEA; 2024 [cited 2026 Jul 24]. Available from: <https://www.iaea.org/topics/biological-control>
 28. Biological control of insect pests in agroecosystems: Current challenges, innovative strategies, and future directions. *MDPI Agriculture*. 2026;16(5):597. Available from: <https://www.mdpi.com/2077-0472/16/5/597>
 29. Pacific Northwest Pest Management Handbooks. Biological control [Internet]. 2026 [cited 2026 Jul 24]. Available from: <https://pnwhandbooks.org/insect/ipm/biological-control>
 30. The pest kill rate of thirteen natural enemies as aggregate evaluation criterion of their biological control potential of *Tuta absoluta*. PubMed Central. 2021; PMC8144571. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8144571/>
 31. Biological control potential of the reduviid predator *Rhynocoris fuscipes* (Fabricius) in managing noctuid pests: Insights into predation and prey preference. PubMed Central. 2025; PMC11856166. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11856166/>
 32. Remote sensing and artificial intelligence: Revolutionizing pest management in agriculture. *Frontiers in Sustainable Food Systems*. 2025. Available from: <https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2025.1551460/full>
 33. A review on role of beneficial insects in sustainable crop production systems. *Journal of Experimental Agriculture International*. 2025;2992. Available from: <https://journaljeai.com/index.php/JEAI/article/view/2992>
 34. Nega W, et al. Climate change impacts on agriculture: A review of plant diseases and insect pests in Ethiopia and East Africa, with adaptation and mitigation strategies. *Advances in Agriculture*. 2025.
 35. The impact of climate change on agricultural insect pests. *Insects*. 2021;12(5):440. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8150874/>
 36. The impact of climate change on insect pest biology and ecology: Implications for pest management strategies, crop production, and food security. ScienceDirect. 2023. Available from: <https://www.sciencedirect.com/science/article/pii/S2666154323002405>
 37. Roadmap for mainstreaming integrated pest management (IPM) into a climate smart one-health (CS-OH) framework. PubMed Central. 2025; PMC12155761. Available from: <https://pmc.ncbi.nlm.nih.gov/articles/PMC12155761/>
 38. Effects of corn-soybean strip intercropping on control efficiency of insect pests and crop yields. PubMed Central. 2025; PMC12609226. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC12609226/>
 39. Water stress and insect herbivory interactively reduce crop yield while the insect pollination benefit is conserved. PubMed Central. 2020; PMC7756552. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7756552/>
 40. Rovensa Next Global. Integrated Pest Management: A sustainable approach to agriculture [Internet]. 2024 [cited 2026 Jul 24]. Available from: <https://www.rovensanext.com/en/news/articles/integrated-pest-management-a-sustainable-approach-to-agriculture/>
 41. Key tropical crops at risk from pollinator loss due to climate change and land use. *Science Advances*. 2023; PMC10569713. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10569713/>
 42. Effects of crop rotation and reduced chemical inputs on pests and predators in maize agroecosystems. *Agriculture, Ecosystems & Environment*. 1994.
 43. Remote sensing and artificial intelligence for crop pest and disease monitoring: A systematic review of sensing technologies, AI approaches, and barriers to field adoption. ScienceDirect. 2026. Available from: <https://www.sciencedirect.com/science/article/pii/S2772375526005046>
 44. Artificial intelligence in entomology: Global advances, applications, and future directions in insect research and pest management. *STM Journals*. 2026. Available from: <https://journals.stmjournals.com/article/article=2026/view=239652/>
 45. University of Florida IFAS EDIS. Intercropping, crop diversity and pest management (ENY862/IN922) [Internet]. UF/IFAS EDIS; 2018 [cited 2026 Jul 24]. Available from: <https://edis.ifas.ufl.edu/publication/IN922>
 46. Zhou W, Arcot Y, Medina RF, Bernal J, Cisneros-Zevallos L, Akbulut MES. Integrated pest management: An update on the sustainability approach to crop protection. *ACS Omega*. 2024; PMC11465254. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11465254/>