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Next-Generation Integrated Pest Management: Integrating AI, Biocontrol and Precision Agriculture

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Integrated Pest Management (IPM) is entering a new phase in which artificial intelligence (AI), biological control, and precision agriculture converge into a single, data-driven system rather than operating as separate, loosely connected practices. AI-powered forecasting and computer-vision monitoring now identify pest risk before outbreaks establish, precision agriculture technologies such as drones, robots, and variable-rate applicators deliver interventions only where and when they are needed, and biocontrol agents - predators, parasitoids, entomopathogens, and molecular tools such as RNA interference (RNAi) and CRISPR-based gene drives - provide targeted, chemical-sparing suppression of pest populations. This article reviews how these three pillars are being integrated into next-generation IPM frameworks, presents field-level evidence of their combined impact, and discusses the ecological, regulatory, and technical challenges that must be addressed for this integration to scale sustainably.

Introduction

Classical Integrated Pest Management combined scouting, economic thresholds, cultural practices, and judicious pesticide use into a single decision framework. While effective, the classical model still depends heavily on human observation and reactive decision-making, and biological and chemical interventions are often planned and applied separately rather than as part of one coordinated system. Global crop losses to pests, pathogens, and weeds remain enormous, and the pressure to reduce chemical inputs while maintaining yields has only intensified as consumers, regulators, and changing climates all push agriculture toward more sustainable practices. A new generation of IPM is emerging in response. Artificial intelligence and the Internet of Things (IoT) now allow pest pressure to be forecast and monitored continuously rather than through periodic scouting, while precision agriculture technologies - drones, autonomous ground robots, and variable-rate applicators - make it possible to act on that information at the scale of an individual plant rather than an entire field. At the same time, biological control is being reshaped by molecular tools such as RNAi and CRISPR-based gene editing, expanding what biocontrol can target and how precisely it can be delivered (Sansinenea et al., 2026). Bringing these three strands together - AI, biocontrol, and precision agriculture - is what defines next-generation IPM.

Pillar One: AI-Driven Forecasting and Decision Support

AI-driven IPM frameworks synthesise data from weather stations, soil sensors, satellite and drone imagery, and networked traps to forecast pest risk before populations reach damaging levels. Review evidence spanning studies published between 2020 and 2026 shows growing use of machine learning, deep learning, edge computing, and UAV-assisted surveillance for pest detection, disease diagnosis, and yield prediction, all feeding into AI-driven decision support systems for precision farming (IPM in the AI era review, 2026). Multi-task AI models are also beginning to unify these functions: shared model backbones can simultaneously classify pests, segment disease lesions, detect weeds, and flag nutrient deficiencies within a single computational framework, allowing a grower to see pest, disease, and crop-stress risk together rather than through separate tools (crop protection AI review, 2026).

Pillar Two: Precision Delivery of Biological Control

Precision agriculture is changing not just how pests are detected but how biocontrol itself is delivered. Rather than releasing predators, parasitoids, or biopesticides uniformly across a field, IoT-enabled detection of pest outbreaks and plant stress now allows biocontrol agents to be deployed at the precise time and location where they will be most effective (IPM in the AI era review, 2026). In one documented citrus canker management programme, AI combined with IoT was used to monitor disease severity, soil nutrients, and yield after applying bioformulations such as *Bacillus velezensis* and *Pseudomonas putida* alongside botanical and organic inputs; AI-assisted assessment showed that *B. velezensis* triggered host defence mechanisms, reduced disease incidence by 81%, and increased yield to 120 fruits per plant, demonstrating the practical value of pairing AI and IoT with biological inputs (IPM in the AI era review, 2026). Augmentative biological control - the mass-rearing and release of natural enemies to suppress pest populations - is itself being modernised through digital, molecular, and precision technologies, with recent advances in mass-rearing and quality control supporting more consistent, scalable releases (augmentative biological control review, 2026).

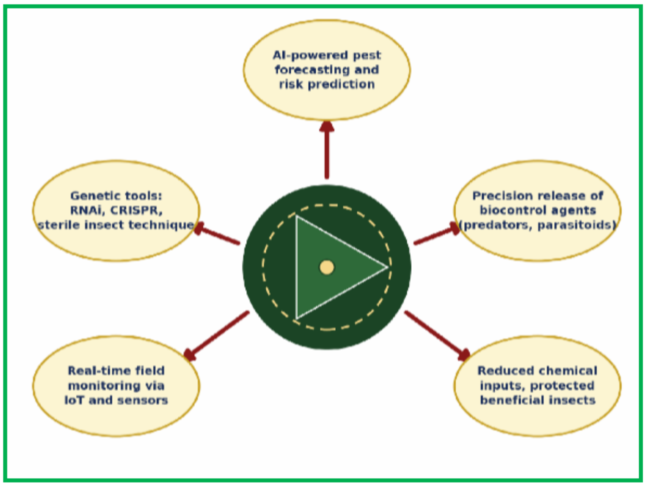

Figure 1. The convergence of AI, biological control, and precision agriculture at the core of next-generation IPM.

Pillar Three: Genetic and Molecular Tools Expanding Biocontrol

Biocontrol itself is being reshaped at the molecular level. Gene drive systems and transgene-generated resistance offer new strategies for targeted, species-specific pest suppression, while emerging delivery platforms for double-stranded RNA (dsRNA) and CRISPR-based tools have broadened the range of genetic approaches available to entomologists (Sansinenea et al., 2026). These techniques raise real ecological and biosafety questions - including species interactions, gene flow, and regulatory approval - and their responsible deployment depends on strong risk governance alongside the underlying synthetic biology (Sansinenea et al., 2026). Complementary innovations in formulation science, including biobased nanoemulsions and nanoclay carriers engineered to stabilise RNAi payloads, are also being developed to improve the shelf-life and field performance of biological pest-control products (eco-friendly biocontrol formulations review, 2026).

Bringing the Pillars Together: Digital Twins and Simulation

A growing area of research uses simulation environments to plan pest management before a single intervention is applied in the field. Agricultural biotic-stress simulation platforms allow researchers to model pest and disease pressure across a season and test different management strategies computationally, supporting what has been described as ultra-precision management planning (AgGym, 2025). Digital twins, edge-enabled recognition systems, and mobile crowdsourcing platforms are converging in a similar direction, combining field-level data collection with real-time analytics to support both localised, farm-level decisions and broader regional pest-risk management (Data-Driven Pest Management review, 2026).

Challenges and Limitations

Despite rapid progress, several barriers stand between today's pilot projects and widespread adoption. Living biocontrol agents remain constrained by shelf-life stability and environmental viability under ambient storage conditions, which limits how easily they can be distributed and stored at scale (eco-friendly biocontrol formulations review, 2026). AI and IoT infrastructure still depends on reliable connectivity and affordable hardware, both of which remain out of reach for many smallholder farmers, while genetic tools such as gene drives and CRISPR-based approaches face genuine regulatory and public-acceptance hurdles that will take time to resolve (Sansinenea et al., 2026). Integrating AI, biocontrol, and precision agriculture into one coherent system also requires interdisciplinary collaboration among entomologists, data scientists, agronomists, and regulators - a coordination challenge that is often underestimated.

Conclusion

Next-generation IPM is not a single technology but the integration of three converging capabilities: AI-driven forecasting and decision support, precision agriculture's ability to act at the scale of an individual plant, and a biocontrol toolkit that now extends from predatory insects to RNAi and gene drives. Early field evidence - from AI-guided biocontrol in citrus orchards to simulation-based management planning - shows that this integration can meaningfully reduce chemical inputs while maintaining or improving yields. Realising its full potential at scale will depend on affordable hardware, robust risk governance for genetic tools, and closer collaboration across the disciplines that make next-generation IPM possible.

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