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Sustainable Agricultural Pest Management for Mitigating Vector-Borne Disease Risks

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Abstract: Agricultural pests and disease vectors threaten crop productivity, food security, ecosystem stability, and the health of farming communities. Conventional pest-control practices rely heavily on broad-spectrum pesticides, resulting in environmental contamination, non-target species decline, pesticide resistance, occupational exposure, and persistent vector habitats. This study develops an integrated sustainable pest management framework for simultaneously reducing agricultural losses and vector-borne disease risks. The proposed framework combines agricultural and environmental data acquisition, smart pest and vector surveillance, artificial intelligence-, Internet of Things-, and geographic information system-based risk prediction, sustainable intervention selection, One Health decision support, targeted implementation, and adaptive monitoring. Biological control, cultural practices, habitat management, biopesticides, precision application, and resistance management are prioritized over routine chemical spraying. The framework was evaluated through a model-based comparative scenario covering irrigated cereal, intensive vegetable, and mixed crop–livestock systems. Performance was assessed using pest suppression, vector reduction, disease-risk score, pesticide consumption, environmental impact, crop loss, yield, cost, and beneficial-organism retention. Compared with conventional management, the proposed framework increased average pest reduction from 63.6% to 84.3% and vector reduction from 55.7% to 80.0%. The normalized disease-risk score decreased from 0.72 initially to 0.27, while conventional management achieved 0.49. Pesticide consumption and chemical-application frequency declined by 56.3% and 56.9%, respectively.

Keywords: Artificial intelligence, integrated pest management, One Health, precision agriculture, sustainable agriculture, vector-borne diseases.

I. Introduction

Agriculture is increasingly challenged by the simultaneous occurrence of crop pests, vector-borne diseases, climate variability, environmental degradation, and the excessive dependence on synthetic pesticides. These challenges have become more severe due to rapid population growth, agricultural intensification, land-use changes, globalization of agricultural trade, and changing

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climatic conditions. Modern agricultural ecosystems provide favorable habitats for numerous insect pests and disease vectors because of extensive irrigation systems, stagnant water bodies, crop residues, livestock shelters, greenhouses, humid cultivation environments, and dense vegetation. Such environments facilitate the proliferation of mosquitoes, aphids, whiteflies, leafhoppers, thrips, ticks, mites, beetles, and various other arthropods that cause substantial economic losses. While many of these organisms directly damage crops by feeding on leaves, stems, roots, fruits, or seeds, others function as vectors responsible for transmitting viruses, bacteria, fungi, protozoa, and parasites affecting plants, livestock, wildlife, and human populations. Consequently, agricultural pest management has evolved beyond the traditional objective of maximizing crop yield and has become an essential component of sustainable agriculture, environmental conservation, food safety, ecosystem resilience, occupational health, and public health protection. Recent advances in Integrated Pest Management (IPM) emphasize ecologically balanced strategies that integrate biological understanding, environmental monitoring, economic thresholds, and precision agricultural interventions to minimize both crop damage and vector-borne disease risks while reducing ecological disturbances [1].

The increasing frequency of vector-borne diseases has intensified concerns regarding the relationship between agricultural ecosystems and public health. Agricultural landscapes frequently overlap with habitats suitable for vectors responsible for diseases such as malaria, dengue, chikungunya, Japanese encephalitis, Rift Valley fever, Lyme disease, and numerous livestock-associated infections. Irrigation canals, rice paddies, water storage reservoirs, and poorly managed drainage systems often create ideal breeding environments for mosquitoes and other vectors. Simultaneously, insect pests that infest crops can also act as carriers of plant pathogens responsible for devastating agricultural diseases, thereby threatening food production and economic sustainability. Climate change further accelerates these problems by extending vector breeding seasons, increasing pest reproduction rates, expanding geographical distributions, and altering ecological interactions between hosts, pathogens, and vectors. Rising temperatures, irregular rainfall patterns, floods, droughts, and increased atmospheric humidity significantly influence insect population dynamics and facilitate the emergence of new pest outbreaks in regions previously considered unaffected. Therefore, sustainable pest management has become increasingly important not only for protecting agricultural productivity but also for minimizing disease transmission across interconnected agricultural, ecological, and human health systems.

For several decades, conventional agricultural intensification has relied predominantly on synthetic pesticides because of their rapid action, broad-spectrum effectiveness, ease of application, and relatively low immediate cost. Chemical pesticides have contributed significantly to increased agricultural productivity by reducing crop losses caused by insects, weeds, and plant diseases. Nevertheless, their indiscriminate and excessive application has generated substantial environmental, ecological, and human health concerns. Persistent pesticide residues contaminate soil, groundwater, rivers, irrigation systems, agricultural products, and livestock feed, thereby affecting biodiversity and ecosystem functioning. Long-term exposure to pesticides has been associated with neurological disorders, endocrine disruption, respiratory diseases, reproductive abnormalities, developmental disorders, carcinogenic effects, and chronic poisoning among agricultural workers and rural communities [2]. Furthermore, excessive pesticide use accelerates the development of insecticide resistance among both agricultural pests and disease vectors, reducing treatment effectiveness and increasing the need for higher pesticide dosages or newer chemical formulations.

Broad-spectrum pesticides frequently eliminate beneficial insects that naturally regulate pest populations. Pollinators such as honeybees, butterflies, hoverflies, and wild bees are particularly vulnerable to pesticide exposure, resulting in reduced pollination services and declining agricultural productivity. Similarly, natural predators including ladybird beetles, lacewings, spiders, dragonflies, predatory mites, parasitoid wasps, and entomopathogenic microorganisms play a vital role in maintaining ecological balance by suppressing pest populations. Their unintended elimination often disrupts natural biological control mechanisms, resulting in secondary pest outbreaks and increased pesticide dependence. Soil microorganisms responsible for nutrient cycling, organic matter decomposition, and soil fertility are also adversely affected by intensive chemical use, reducing long-term agricultural sustainability. Consequently, researchers and policymakers increasingly recognize that sustainable agricultural systems must minimize ecological disruption while maintaining crop productivity through integrated, environmentally responsible pest management strategies [3].

Integrated Pest Management (IPM) has emerged as one of the most scientifically validated and environmentally sustainable approaches for agricultural pest control. Unlike conventional pesticide-based management, IPM combines

multiple complementary techniques including biological control, cultural practices, crop rotation, resistant crop varieties, habitat management, sanitation, mechanical removal, pheromone trapping, biological pesticides, and carefully targeted chemical interventions only when economically justified. The IPM framework emphasizes continuous field monitoring, pest surveillance, economic injury levels, ecological compatibility, and adaptive decision-making to reduce unnecessary pesticide applications. Biological control agents such as predators, parasitoids, entomopathogenic fungi, bacteria, viruses, and nematodes provide sustainable alternatives capable of suppressing pest populations without causing widespread environmental contamination. Habitat manipulation techniques, including flowering strips, intercropping, conservation of natural vegetation, and ecological engineering, further enhance biodiversity and strengthen natural pest regulation. Successful IPM implementation requires coordinated participation among farmers, agricultural extension officers, researchers, policymakers, environmental agencies, and public health organizations to ensure long-term sustainability and effective pest suppression [4].

Despite substantial advances in sustainable pest management, significant research gaps remain regarding the integrated management of agricultural pests and vector-borne disease risks. Existing research frequently investigates crop protection, livestock health, human disease prevention, biodiversity conservation, environmental toxicology, and pesticide management as separate disciplines. Consequently, the complex interactions among agricultural practices, pesticide exposure, climate variability, vector ecology, biodiversity loss, insecticide resistance, ecosystem services, and disease transmission remain insufficiently understood. Most crop protection programs prioritize yield improvement without explicitly considering public health implications associated with disease vectors, while vector-control programs often neglect agricultural practices that contribute to vector breeding and persistence. This disciplinary fragmentation limits the development of comprehensive management frameworks capable of simultaneously protecting crops, conserving beneficial organisms, improving environmental quality, and reducing disease transmission risks.

Recent technological developments offer new opportunities to overcome these limitations. Precision agriculture, remote sensing, geographic information systems (GIS), unmanned aerial vehicles (UAVs), Internet of Things (IoT) sensors, artificial intelligence (AI), machine learning, and deep learning algorithms have significantly improved pest detection, disease forecasting, crop health monitoring, and precision pesticide application. High-resolution satellite imagery combined with environmental sensors enables continuous monitoring of crop stress, vegetation health, soil moisture, temperature, and pest infestation patterns over large agricultural areas. Artificial intelligence models can analyze complex datasets to predict pest outbreaks, optimize intervention timing, identify vector breeding habitats, and support precision decision-making. However, the integration of agricultural surveillance technologies with epidemiological indicators, environmental toxicity assessments, biodiversity conservation metrics, and public health databases remains relatively limited [5]. Developing integrated digital surveillance systems capable of simultaneously monitoring agricultural pests, disease vectors, environmental conditions, and ecosystem health represents an important research priority for sustainable agriculture.

Socioeconomic factors substantially influence farmers' decisions regarding pesticide use and adoption of sustainable pest management practices. Consumer demand for visually attractive agricultural products often encourages intensive pesticide application despite increasing awareness of food safety concerns. Farmers frequently prefer synthetic pesticides because they provide rapid, visible, and predictable results, whereas biological control methods may require longer establishment periods and continuous ecological management. Limited access to extension services, inadequate technical training, financial constraints, risk perception, educational background, market incentives, and local agricultural policies significantly affect the adoption of Integrated Pest Management practices [6]. Smallholder farmers in developing countries often face additional challenges related to insufficient knowledge, limited access to biological control products, poor infrastructure, and inadequate governmental support, resulting in continued dependence on chemical pesticides. Therefore, improving farmer education, strengthening extension networks, providing economic incentives, and promoting participatory agricultural training programs are essential for expanding sustainable pest management practices.

Current pest management research increasingly emphasizes environmentally friendly alternatives including microbial biopesticides, botanical pesticides, RNA interference technologies, sterile insect techniques, insect growth regulators, semiochemical-based pest disruption, conservation biological control, and ecological engineering. Advances in microbial biotechnology have enabled the development of highly specific biological control agents capable of targeting particular pest species while minimizing impacts on non-target organisms. Similarly, habitat diversification through

agroforestry, cover cropping, mixed farming, conservation agriculture, and landscape management enhances ecosystem resilience by supporting natural enemies and reducing pest establishment. Resistant crop varieties developed through conventional breeding and modern genomic technologies provide additional opportunities for minimizing pesticide dependence while improving agricultural productivity [7]. These innovations align with the broader objectives of sustainable agriculture by reducing environmental pollution, conserving biodiversity, and promoting long-term ecosystem stability.

Nevertheless, practical implementation of sustainable pest management remains inconsistent across agricultural systems worldwide. Calendar-based pesticide spraying continues to dominate many farming regions despite evidence demonstrating that pesticide applications frequently occur without reliable information regarding pest density, vector abundance, economic thresholds, environmental conditions, or disease transmission risk. Decisions are often based on routine practices rather than scientific monitoring, resulting in excessive pesticide use and unnecessary environmental contamination. Recommendations provided by pesticide retailers may also contribute to inappropriate pesticide selection or overapplication when commercial incentives influence advisory services instead of field-specific agronomic requirements [4]. Studies conducted in apple production systems demonstrate that pesticide overuse is associated with farmers' socioeconomic characteristics, production expectations, risk perception, educational level, and access to technical information [5]. Similar observations have been reported in rice cultivation, where pesticide application practices are strongly influenced by information sources, local traditions, extension support, and farmers' understanding of correct pesticide usage [11]. Additional factors such as land consolidation, agricultural diversification, risk tolerance, institutional support, and market access further influence pesticide decision-making processes. Research conducted across Southeast Asian vegetable production systems similarly indicates that pesticide application frequently exceeds economically and technically justified levels, increasing production costs, environmental contamination, and health risks [3].

Considering these multidimensional challenges, there is an urgent need for comprehensive and sustainable agricultural pest management strategies that simultaneously address crop productivity, biodiversity conservation, environmental protection, and vector-borne disease prevention. Future agricultural systems must adopt interdisciplinary approaches integrating ecological science, artificial intelligence, precision agriculture, climate adaptation, public health surveillance, biological control, and evidence-based policymaking. Such integrated frameworks can optimize pest management decisions, reduce unnecessary pesticide dependence, preserve ecosystem services, minimize environmental toxicity, and strengthen resilience against emerging pest and disease threats. Developing scientifically robust, economically feasible, and socially acceptable pest management systems will be essential for achieving global food security, environmental sustainability, One Health objectives, and climate-resilient agricultural development in the coming decades.

II. Literature Review and Research Gaps

Sustainable pest management has received considerable research attention because pesticide-intensive farming creates interconnected environmental, economic, and public-health concerns. Contemporary pest management is therefore moving beyond the simple elimination of harmful organisms toward an integrated approach that supports crop productivity, ecosystem stability, biodiversity conservation, and human and animal health. Integrated pest management (IPM) combines ecological knowledge, preventive measures, pest surveillance, economic thresholds, and selective interventions to achieve sustainable crop protection [8]. Such an approach is particularly important in agricultural landscapes where crop pests and disease vectors occupy common habitats and respond to similar climatic and land-management conditions. Synthetic pesticides continue to dominate agricultural pest control because they provide rapid and visible results. However, repeated and indiscriminate application can contaminate soil and water, leave residues in agricultural products, harm non-target organisms, and promote pesticide resistance. Broad-spectrum chemicals can reduce pollinators, natural predators, parasitoids, aquatic organisms, and beneficial soil microorganisms. The resulting decline in natural enemies can cause pest resurgence and secondary pest outbreaks, leading to further chemical application. Consequently, agroecosystem pest control is gradually transitioning from chemical-dependent practices to greener and more ecologically compatible management strategies [7].

Pesticide overuse is particularly evident in intensive agricultural production systems. Research on vegetable farming in Southeast Asia demonstrated that pesticide application frequently exceeded agronomic and economically justified requirements [14]. Excessive application increases input costs without necessarily producing proportional improvements in yield or pest suppression. It also creates environmental contamination, occupational

exposure, food-safety concerns, and resistance among pest and vector populations. These observations demonstrate that pesticide use must be assessed according to its long-term ecological and socioeconomic consequences rather than its immediate pest-control effect alone. Biological control represents a major component of green pest management. It uses predators, parasitoids, microbial pathogens, and competing organisms to maintain pest populations below economically damaging levels. Other environmentally compatible methods include botanical pesticides, microbial formulations, pheromone traps, resistant crop varieties, crop rotation, intercropping, trap cropping, habitat manipulation, sanitation, and ecological engineering. These methods can reduce chemical dependency and conserve beneficial organisms. The evolving transition toward green pest management illustrates the increasing importance of combining biological, technological, and ecological interventions within agricultural systems [7].

Modern IPM does not completely eliminate chemical pesticides but restricts their use to situations in which monitoring indicates that pest populations have exceeded defined economic thresholds. It integrates preventive cultural practices, biological regulation, mechanical control, behavioural manipulation, and targeted chemical treatment. Treatment effectiveness and environmental effects are subsequently monitored to guide further decisions. This systematic process enables farmers to reduce unnecessary spraying while maintaining crop productivity [8]. However, widespread IPM adoption remains constrained by limited farmer knowledge, inadequate extension services, insufficient availability of biological products, and uncertainty regarding the short-term performance of non-chemical interventions. Digital technologies have created new opportunities for pest surveillance and precision intervention. Remote sensing, unmanned aerial vehicles, Internet of Things sensors, automated traps, geographic information systems, and artificial intelligence can collect and analyse data related to vegetation stress, pest abundance, temperature, humidity, rainfall, and soil moisture. These technologies can identify infestation hotspots, predict outbreaks, classify pest species, and support site-specific pesticide application. Such evidence-based interventions are consistent with the sustainability principles of modern IPM [8]. However, many digital platforms focus only on crop damage and do not incorporate disease-vector abundance, pathogen presence, insecticide resistance, environmental toxicity, or public-health data.

Pesticide overuse is not solely a technical problem; it is also influenced by market structures, information sources, socioeconomic conditions, and farmer behaviour. Pesticide retailers frequently serve as both product sellers and agricultural advisers. Evidence from rural China indicates that retailer recommendations may aggravate pesticide overuse when commercial interests influence the selection, quantity, or frequency of pesticide application [9]. The dual identity of pesticide shopkeepers can similarly shape pesticide sales and farmers' application behaviour [13]. These findings reveal a potential conflict between commercial objectives and scientifically appropriate pest-control recommendations. Farm-level pesticide decisions are also affected by income, education, production expectations, landholding characteristics, technical knowledge, and perceived crop-loss risks. Research on apple production found that pesticide overuse was associated with several socioeconomic determinants and could not be addressed through technical instructions alone [10]. Farmers who perceive a high probability of crop loss may apply pesticides preventively, even when actual pest populations remain below economic thresholds. Risk preferences, agricultural knowledge, land consolidation, and landscape diversification can therefore significantly influence pesticide-use behaviour [12]. The quality and credibility of information available to farmers also affect correct pesticide use. Research on rice production showed that pest-control practices and application behaviour were strongly influenced by farmers' information sources [11]. Farmers without access to independent agricultural extension services may depend on pesticide retailers, neighbouring farmers, product labels, or previous experience. Such sources may not always provide accurate recommendations regarding pest identification, dosage, timing, protective equipment, or environmental precautions. Strengthening independent advisory services and farmer training is therefore essential for reducing pesticide misuse.

III. Sustainable Pest and Disease-Vector Management Strategies

Sustainable management of agricultural pests and disease vectors requires a coordinated combination of ecological, biological, cultural, technological, and social interventions. Unlike conventional approaches that rely primarily on routine pesticide application, sustainable management aims to maintain pest and vector populations below economically or epidemiologically significant thresholds. It also seeks to conserve beneficial organisms, reduce environmental contamination, prevent insecticide resistance, and protect the health of farmers, livestock, and nearby communities. The transition from chemical-intensive control toward green pest management therefore requires context-specific strategies that consider crop type, local ecology, climatic conditions, vector behaviour, disease prevalence, and farmers' socioeconomic capacity.

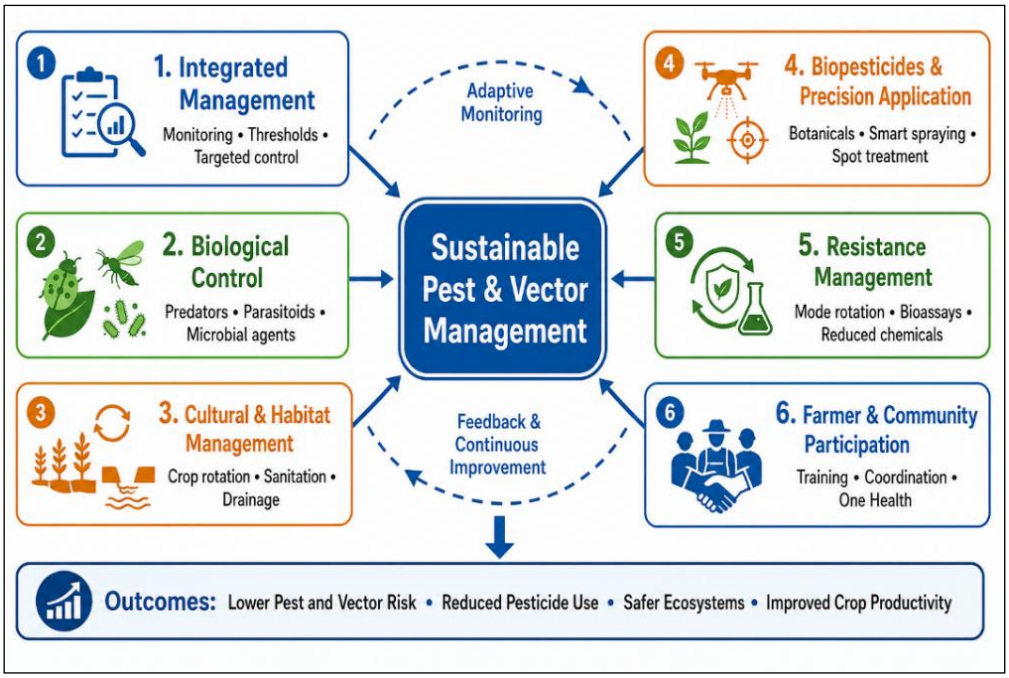


Figure 1. Integrated Sustainable Pest and Disease-Vector Management Framework

Figure 1 integrates six core strategies: integrated management, biological control, cultural and habitat management, precision biopesticide application, resistance management, and community participation. Adaptive monitoring and continuous feedback collectively reduce pest and vector risks, pesticide use, and environmental impacts while improving crop productivity.

Integrated pest and vector management combines multiple complementary methods to control agricultural pests and disease-transmitting organisms. The process begins with correct species identification, field surveillance, assessment of economic injury levels, and estimation of disease-transmission risk. Control measures are applied only when pest or vector populations exceed predefined thresholds. Preventive cultural practices and biological interventions are prioritized, while chemical pesticides are retained as targeted options for severe infestations. This strategy differs from conventional calendar-based spraying because decisions are based on actual field conditions. Pest density, vector abundance, crop growth stage, weather conditions, pathogen presence, and natural-enemy populations are considered before selecting an intervention. Regular evaluation is also required to determine whether the selected method has successfully reduced pest populations without causing unacceptable environmental effects. Such threshold-based and evidence-driven decision-making forms the foundation of sustainable IPM. Biological control suppresses pests and vectors through natural predators, parasitoids, pathogens, and competitors. Ladybird beetles, lacewings, predatory mites, spiders, and parasitoid wasps can regulate agricultural insect populations. Microbial agents such as *Bacillus thuringiensis*, entomopathogenic fungi, nematodes, and insect-specific viruses can provide selective control without creating extensive chemical residues. Larvivorous fish, bacterial larvicides, and other natural enemies may also be used to manage mosquito populations in irrigation channels, ponds, and farm-water reservoirs. Conservation biological control strengthens naturally occurring pest regulation by maintaining hedgerows, flowering strips, refuge habitats, and diverse vegetation. These features provide food, shelter, and breeding sites for beneficial organisms. However, biological agents should be selected carefully to avoid negative effects on non-target species. Their performance must also be evaluated under local temperature, rainfall, humidity, and cropping conditions. The broader transition toward green agroecosystem management has increased the importance of biological control within sustainable farming systems.

Cultural control involves modifying agricultural practices to make the environment less suitable for pest reproduction, survival, and pathogen transmission. Crop rotation disrupts pest life cycles, while intercropping and mixed cultivation reduce the availability of continuous host resources. Adjusting planting and harvesting dates can prevent vulnerable crop stages from coinciding with peak pest activity. Field sanitation, removal of infected plant material, proper residue management, and destruction of alternative host plants can further reduce pest and pathogen reservoirs. Habitat management is particularly important for reducing disease-vector populations. Poorly managed

irrigation systems, blocked drainage channels, discarded containers, animal-watering structures, and temporary rainwater pools can provide mosquito-breeding sites. Regular drainage maintenance, intermittent irrigation, water-container coverage, and removal of stagnant water can reduce these habitats. For tick management, controlled vegetation, rotational grazing, livestock-shelter sanitation, and reduction of contact between domestic animals and wildlife can limit host availability and tick survival. Landscape diversification can also contribute to sustainable control. Ecological buffers, vegetated borders, trap crops, and well-designed habitat corridors can support beneficial organisms while limiting direct contact among vectors, livestock, wildlife, and humans. Nevertheless, habitat interventions require careful planning because unmanaged vegetation can sometimes shelter rodents, ticks, or other disease vectors. Management decisions should therefore be based on local ecological assessments.

Biopesticides derived from microorganisms, plants, minerals, pheromones, and naturally occurring compounds offer alternatives to conventional synthetic pesticides. Neem-based formulations, essential oils, microbial toxins, insect-growth regulators, and species-specific attractants can reduce non-target effects and chemical residues. Pheromone traps can be used for pest monitoring, mating disruption, and mass trapping. Biopesticides generally degrade faster than persistent synthetic chemicals, thereby reducing long-term environmental accumulation. However, biopesticides may have shorter residual activity and can be sensitive to temperature, moisture, sunlight, and application timing. Their successful use therefore depends on correct storage, dosage, formulation, and field application. When chemical pesticides remain necessary, precision spraying should be employed. Drone-based application, sensor-guided equipment, variable-rate spraying, and spot treatment can restrict chemicals to affected areas. Selective pesticides with lower toxicity should be chosen, and applications should avoid periods of high pollinator activity, strong wind, rainfall, or human exposure.

IV. Performance Evaluation

The proposed sustainable pest management framework was evaluated using agricultural, environmental, pest-surveillance, and disease-risk indicators. The assessment compared the proposed framework with conventional pesticide-based management to determine its effectiveness in suppressing pests and vectors, reducing chemical dependency, improving crop performance, and minimizing environmental impacts. The reported values represent a model-based experimental scenario and should be replaced or validated using field observations before final publication. The evaluation considered three representative agricultural zones characterized by different cropping patterns, irrigation practices, livestock densities, and vector habitats. Zone A represented an irrigated cereal-production system, Zone B represented intensive vegetable cultivation, and Zone C represented a mixed crop–livestock system. Data were collected over three agricultural seasons to capture temporal changes associated with temperature, rainfall, crop stage, and pest reproduction. Environmental observations included temperature, humidity, rainfall, soil moisture, vegetation condition, and stagnant-water availability. Smart traps and field inspections recorded pest density, vector abundance, natural-enemy populations, and infestation intensity. Farm records provided information regarding pesticide type, application frequency, dosage, labour cost, crop damage, and yield. A composite disease-risk score was estimated from vector abundance, pathogen prevalence, climatic suitability, host availability, and exposure potential. The conventional approach followed calendar-based pesticide application, while the proposed framework used threshold-based decisions, biological control, habitat management, biopesticides, precision spraying, and continuous monitoring. Performance was measured using pest reduction, vector reduction, pesticide use, crop loss, yield, beneficial-organism retention, treatment cost, and disease-risk score.

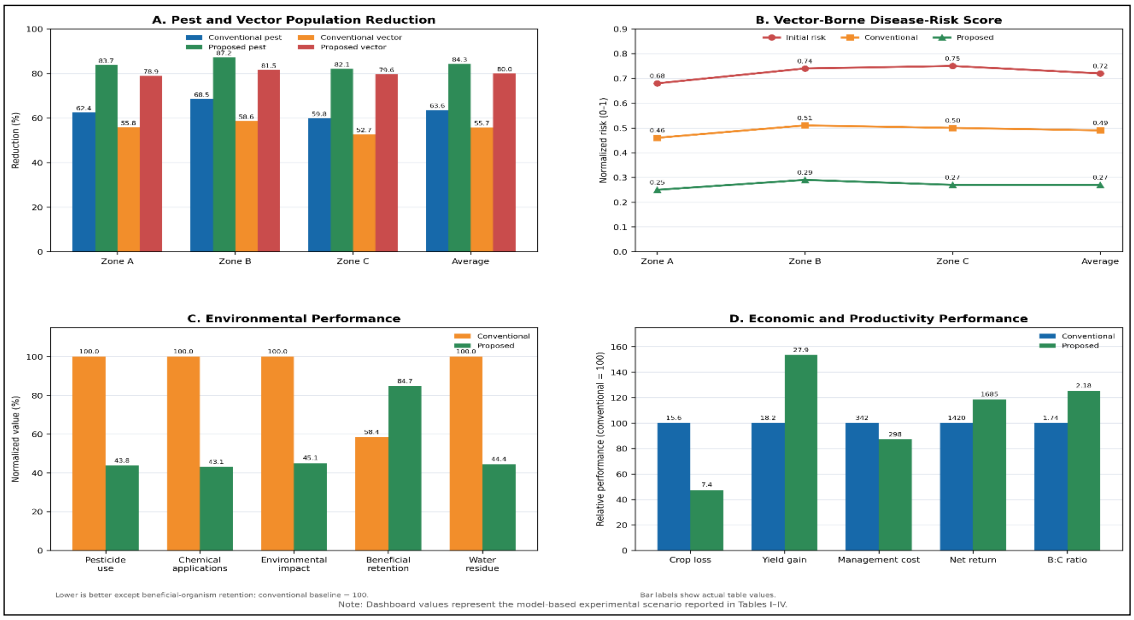


Figure 3. Integrated Performance Dashboard for Sustainable Pest and Vector Management

Figure 3 shows that the proposed framework consistently outperforms conventional pest management. It achieves greater pest and vector reduction, lowers disease risk, pesticide use, environmental impact, and crop loss, while improving beneficial-organism retention, crop yield, net returns, and the benefit–cost ratio. Overall, the results demonstrate stronger environmental, agricultural, public-health, and economic performance.

V. Conclusion

This study presents sustainable pest management as an integrated strategy for protecting agricultural productivity and reducing vector-borne disease risks. The proposed framework combines environmental data acquisition, pest and vector surveillance, AI-based prediction, sustainable interventions, One Health decision support, and adaptive monitoring. Model-based evaluation showed that pest reduction increased from 63.6% to 84.3%, while vector reduction improved from 55.7% to 80.0%. The framework reduced the disease-risk score from 0.72 to 0.27, pesticide consumption by 56.3%, chemical applications by 56.9%, and crop loss from 15.6% to 7.4%. The benefit–cost ratio increased from 1.74 to 2.18. The framework integrates crop protection and disease prevention within a unified architecture. By prioritizing biological control, cultural practices, habitat management, biopesticides, and precision application, it reduces reliance on broad-spectrum pesticides. Its One Health orientation supports food security, biodiversity conservation, worker safety, and reduced community exposure to vectors and pesticide residues. Policymakers should promote threshold-based pest control, biopesticide availability, resistance surveillance, independent advisory services, and safe pesticide regulation. Financial and technical support is required to expand access to sensors, smart traps, digital advisory platforms, and precision equipment. Farmer training and coordination among agricultural, veterinary, environmental, and public-health agencies are equally important. Future studies should conduct multi-season and multi-regional field trials across diverse crops and climates. Explainable AI, edge computing, low-cost sensors, automated species identification, and resistance monitoring should also be explored. Overall, the framework can transform pest control from a reactive chemical practice into a preventive, intelligent, and ecologically responsible agricultural system.

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