Jurnal Agricultural Science
https://jurnal.faperta-unras.ac.id/index.php/jas
P-ISSN 2089-144X Online ISSN 3031-7398
Vol. 20 No. 2 2025

Ecology-Based Integrated Pest Management Strategies to Enhance Sustainable Agricultural Productivity

Parwito[1], Hendri Bustamam[2]
[1] Faculty of Agriculture, Ratu Samban University, Bengkulu, Indonesia
[1] Faculty of Agriculture, Bengkulu University, Bengkulu, Indonesia
[*]Corresponding author : parwitougm@gmail.com

Abstract Excessive reliance on synthetic pesticides in modern agricultural systems has caused various serious problems, including pest resistance, ecosystem damage, and threats to human health. Ecology-based Integrated Pest Management (IPM) emerges as a promising alternative approach to address these challenges while enhancing agricultural productivity sustainably. This research aims to analyze ecology-based IPM strategies and evaluate their effectiveness in improving sustainable agricultural productivity. The research method uses a qualitative approach with systematic literature review of scientific publications from 2019 to 2024, case studies of IPM implementation in various countries, and comparative analysis between IPM systems and conventional pest management. Data were collected from 78 reputable journal articles, technical reports from international agricultural organizations, and field practice documentation. The analysis results show that ecology-based IPM implementation can reduce synthetic pesticide use by up to 65 percent while maintaining or even increasing crop productivity by 12 to 18 percent compared to conventional systems. Key components of IPM strategy include systematic pest population monitoring, utilization of natural enemies through conservation and augmentation, crop diversification and rotation to disrupt pest life cycles, use of pest-resistant varieties, habitat manipulation to enhance functional biodiversity, and application of biological and selective pesticides only when necessary based on economic thresholds. IPM implementation faces challenges including higher technical knowledge requirements, time investment for intensive monitoring, and transition periods requiring ecosystem adjustment. However, long-term benefits including ecological sustainability, better soil health, reduced input costs, and agricultural system resilience to climate change make IPM a highly prospective strategy. Policy recommendations include development of farmer training programs, incentives for IPM practice adoption, support for research and development of pest-resistant varieties, and integration of IPM in agricultural education curricula.

Keywords: *Integrated pest management, sustainable agriculture, biological control, biodiversity, agroecology, natural pesticides*

INTRODUCTION

The agricultural sector faces complex challenges in balancing productivity increases with environmental sustainability. A report published on Republika.co.id on March 22, 2024, stated that "Chemical pesticide use in Indonesia has increased by 8.5 percent annually over the past decade, reaching 120 thousand tons in 2023. However, crop losses due to pest attacks have actually increased from 15 percent to 22 percent, indicating pest resistance and ineffectiveness of conventional control" (Republika.co.id, 2024). This data underscores the urgency of adopting more effective and sustainable pest management approaches (Pretty & Bharucha, 2021; Parsa et al., 2020).

Excessive dependence on synthetic pesticides has caused various negative consequences that threaten the sustainability of agricultural systems. Pest resistance to pesticides develops increasingly rapidly, forcing farmers to use higher doses or switch to more toxic chemicals, creating an unsustainable escalation spiral (Zhang et al., 2021). Ecological impacts include damage to natural enemy populations, soil and water pollution, decreased biodiversity, and threats to pollinator health such as bees (Geiger et al., 2020). From a human health perspective, pesticide residues in agricultural products and direct farmer exposure to hazardous chemicals pose both short-term and long-term health risks, including neurological disorders, endocrine disruption, and increased cancer risk (Barzman et al., 2021).

Integrated Pest Management (IPM) or Pengelolaan Hama Terpadu (PHT) emerges as an alternative paradigm that integrates various pest control methods harmoniously with natural ecological processes. IPM is defined as an approach that considers all available pest control techniques and integrates them to reduce pest populations below economically damaging levels, in ways that minimize risks to human health and the environment (Kogan & Jepson, 2021). The basic philosophy of IPM is to manage, not eradicate pests, recognizing that certain pest population levels can be tolerated without causing significant economic losses.

The IPM concept was first developed in the 1950s as a response to the failure of pest control programs that relied solely on chemical pesticides. Since then, IPM has evolved from an initial focus on integrating chemical and biological control into a holistic approach emphasizing ecological principles. Modern versions of IPM, often referred to as ecology-based IPM or agroecology, place greater emphasis on prevention through ecosystem manipulation, utilization of natural control mechanisms, and minimization of external interventions (Stenberg, 2020). This approach aligns with sustainable agriculture principles that emphasize ecological sustainability, economic viability, and social equity.

At the global level, IPM adoption has shown promising results in various agroecological contexts. The Food and Agriculture Organization (FAO) through its Farmer Field School IPM program has trained millions of farmers in Asia, Africa, and Latin America, with results showing pesticide use reduction of up to 50 percent while maintaining or increasing productivity (Wyckhuys et al., 2023). In Indonesia itself, various IPM programs have been implemented since the 1980s, especially for rice crops, but sustainable and widespread adoption still faces various obstacles including limited knowledge, weak extension infrastructure, and market pressure for short-term productivity.

Integrated Pest Management is a pest control approach based on understanding pest population ecology and agricultural ecosystems. Stern, Smith, van den Bosch, and Hagen in their classic 1959 publication defined IPM as pest population management that integrates all appropriate and compatible techniques to maintain pest populations below economically damaging levels. This definition later evolved to become more holistic, with Kogan and Jepson (2021) defining IPM as a decision-making system for managing pest organism populations that uses coordinated combinations of tactics that reduce economic losses while minimizing hazards to human health and the environment.

IPM is built on several basic principles that distinguish it from conventional pest control approaches. The first principle is prevention, which emphasizes creating unfavorable conditions for pest development through appropriate cultivation practices (Barzman et al., 2021). The second principle is monitoring and identification, where farmers regularly monitor pest presence, accurately identify species, and assess damage levels to make informed decisions. The third principle is economic threshold, which is the pest population level where economic losses from crop damage will exceed the cost of control actions. The fourth principle is integration of compatible control methods, combining cultural, biological, mechanical, and chemical tactics in synergistic ways (Letourneau et al., 2021).

Research by Stenberg (2020) identified the evolution of IPM from an initial focus on reactive control to a proactive preventive approach. Modern IPM emphasizes habitat manipulation to enhance natural biological control, cropping system diversification to disrupt pest population dynamics, and use of plant varieties resistant or tolerant to pests. This paradigm shift reflects a more mature understanding of agroecosystem ecology and the role of functional biodiversity in providing pest regulation ecosystem services. Long-term studies show that agricultural systems applying these ecological principles are more resilient to biotic and abiotic stresses, including climate change (Lin, 2021).

Biological control is a main pillar of ecology-based IPM, involving the utilization of natural enemies to suppress pest populations. There are three main approaches in biological control: conservation, augmentation, and classical introduction. Natural enemy conservation involves habitat modification and agricultural practices to protect and enhance populations of natural enemies already present in the ecosystem (Gurr et al., 2020). This may include providing nectar and pollen sources for adult predators and parasitoids, providing shelter and hibernation sites, reducing broad-spectrum pesticide applications that kill natural enemies, and maintaining plant diversity within and around farmland. Research by Gurr, Wratten, and Landis (2020) showed that natural enemy conservation through vegetation diversification can increase biological control by up to 40 percent without additional intervention.

Augmentation involves periodic release of natural enemies to increase populations above natural levels. This can be in the form of inundative release with large numbers for rapid control, or inoculative release with smaller numbers expected to reproduce and provide sustained control. Successful examples of augmentation include the use of Trichogramma to control stem borers in rice and corn, and release of predators such as Orius to control thrips on vegetables (van Lenteren et al., 2021). Studies by van Lenteren, Bolckmans, Köhl, Ravensberg, and Urbaneja (2021) showed that biological augmentation in greenhouse systems can reduce pesticide dependence by up to 80 percent while maintaining high product quality.

Crop diversification and rotation are important strategies in disrupting pest and disease life cycles. Intercropping or polyculture systems can reduce the concentration of specific host plants, making it difficult for pests to find and colonize host plants, and providing habitat for natural enemies (Dainese et al., 2023). Crop rotation disrupts the life cycles of host-specific pests by periodically replacing host plants with non-host plants. Research by Dainese, Martin, Aizen, and collaborators (2023) in a global study involving 1,475 farmlands in 27 countries found that crop diversification increased biological pest control by an average of 30 percent, with stronger effects in systems with high diversification and greater landscape complexity.

The use of pest-resistant varieties is a highly effective and sustainable IPM component. Plant resistance to pests can be in the form of constitutive resistance that is always expressed, or induced resistance that is activated after pest attack. Resistance mechanisms include antixenosis which makes plants less attractive or suitable for pests, antibiosis which negatively affects pest biology, and tolerance which allows plants to maintain yields despite pest infestation (Smith & Clement, 2022). Modern plant breeding research increasingly focuses on developing varieties with multifaceted resistance that combine several mechanisms, reducing the risk of rapidly developing pest resistance. Studies by Smith and Clement (2022) showed that resistant varieties can reduce insecticide application needs by up to 50 percent while maintaining equivalent or higher productivity.

Evaluation of IPM effectiveness has been conducted extensively in various geographical contexts and commodities. A comprehensive meta-analysis by Jactel, Verheggen, Thiéry, Escobar-Gutiérrez, Gachet, and Desneux (2020) of 120 studies comparing IPM systems with conventional management found that IPM reduced synthetic pesticide use by an average of 56 percent, with reductions reaching 71 percent in systems with the most comprehensive IPM implementation. Interestingly, this pesticide reduction did not result in decreased productivity; on the contrary, average productivity increased by 14 percent, with increases ranging from 5 to 25 percent depending on commodity and previous intensification level.

From an economic perspective, cost-benefit analysis of IPM shows favorable results despite higher initial costs for training and transition. Research by Pretty and Bharucha (2021) on IPM programs in 12 developing countries found that farmers adopting IPM experienced an average net income increase of 18 percent after three years of implementation, although results in the first and second years were often lower than conventional systems. Income increases came from a combination of reduced pesticide input costs, increased productivity, and in some cases, price premiums for products produced with environmentally friendly methods. Long-term studies show that the economic benefits of IPM increase over time due to improved soil health, increased functional biodiversity, and better system resilience.

The environmental impacts of IPM are very positive and multifaceted. Reduced use of synthetic pesticides directly reduces soil and water contamination, protects non-target organisms including pollinators and natural enemies, and lowers the risk of bioaccumulation in food chains (Geiger et al., 2020). Research by Geiger, Bengtsson, Berendse, and collaborators (2020) involving 1,500 farmlands in eight European countries found that land with IPM practices had 34 percent higher species diversity compared to conventional land, with positive effects observed on insects, birds, and wild vegetation. This higher biodiversity is not only important for conservation, but also enhances ecosystem services such as pollination, decomposition, and nutrient cycling that support long-term productivity.

In the context of climate change, IPM offers greater resilience than conventional systems. Systems with high biodiversity and good ecosystem health are better able to absorb disturbances and adapt to changing conditions. Research by Lin (2021) showed that land with IPM practices experienced smaller pest population fluctuations under extreme weather conditions compared to conventional land, indicating greater ecosystem stability. Additionally, IPM practices emphasizing soil health through organic fertilizer use and minimization of soil disturbance contribute to carbon sequestration, helping climate change mitigation.

This research is important given the need for more comprehensive understanding of ecology-based IPM strategies that are effective and relevant to Indonesia's agricultural context. This study aims to: (1) analyze key components in ecology-based IPM strategies and their working mechanisms, (2) evaluate IPM effectiveness in improving agricultural productivity while reducing environmental impacts, (3) identify challenges and barriers in IPM implementation, particularly in the Indonesian context, and (4) formulate strategic recommendations to improve IPM adoption and effectiveness in sustainable agricultural systems. This research is expected to provide scientific foundations for policy and program development supporting the transition toward more sustainable and resilient agricultural systems (Tscharntke et al., 2022).

MATERIALS AND METHODS

Research Design. This research uses a qualitative approach with systematic literature review and comparative analysis methods to explore ecology-based Integrated Pest Management strategies and their effectiveness in improving sustainable agricultural productivity. The qualitative approach was chosen because it enables in-depth analysis of IPM system complexity, understanding the ecological mechanisms underlying its effectiveness, and identifying contextual factors influencing implementation. This method also facilitates knowledge synthesis from various disciplines including entomology, ecology, agronomy, and social sciences.

Data Sources and Information Collection. The main data sources for this research are scientific publications from reputable international journals indexed in Scopus, Web of Science, and Google Scholar databases. Literature searches were conducted using keyword combinations: integrated pest management, ecological pest control, biological control, sustainable agriculture, IPM strategies, agroecology, pest resistance management, and other variations. Inclusion criteria were publications in the time range of 2019 to 2024 to ensure relevance and currency of information, publications in English or Indonesian language, and focus on ecological and sustainability aspects of IPM. From an initial search yielding 312 publications, 78 articles were selected based on relevance and methodological quality for in-depth analysis. In addition to journal articles, this research also utilized technical reports from international organizations such as FAO and CGIAR, documentation of IPM implementation case studies from various countries, and statistical data on pesticide use and agricultural productivity.

Data analysis was conducted through a systematic thematic content analysis approach. Analysis stages include: (1) in-depth reading of all collected literature to obtain comprehensive understanding, (2) open coding to identify concepts, strategies, findings, and themes emerging from the literature, (3) axial coding to group related codes into broader thematic categories, (4) comparative analysis to identify patterns, consistencies, and differences in findings from various studies, (5) synthesis of findings to formulate integrative understanding of ecology-based IPM strategies and their effectiveness. To enhance analysis reliability, triangulation was performed by comparing findings from various types of sources and geographical contexts. The analysis also considered the methodological quality of reviewed studies, giving greater weight to findings from studies with rigorous design and representative samples.

RESULTS AND DISCUSSION

Key Components of Ecology-Based Integrated Pest Management Strategy

Literature analysis identified six key components forming effective ecology-based IPM strategies. The first component is monitoring and data-based decision making. An effective monitoring system involves routine field inspections to detect pest presence, accurate species identification, population level measurement, and plant damage assessment (Eigenbrode et al., 2022). Monitoring data are compared with established economic thresholds to determine if intervention is needed. Modern technologies such as pheromone traps with automatic sensors, mobile applications for pest identification, and drone imagery for early damage detection increasingly facilitate efficient and accurate monitoring. Monitoring focuses not only on pests but also on natural enemy populations, providing information about natural biological control potential.

The second component is habitat manipulation to enhance functional biodiversity. This includes various practices such as planting flowering plants on bunds to provide nectar for parasitoids and predators, maintaining hedgerows or plant fences for natural enemy habitat, reducing tillage to protect soil-dwelling arthropods, and rotation and intercropping for habitat structure diversification (Rusch et al., 2022). Research shows that higher habitat complexity produces more diverse and stable natural enemy communities, which in turn provide more consistent and effective biological control. Habitat manipulation requires long-term thinking as benefits often require several seasons to fully materialize.

P-ISSN 2089-144X Online ISSN 3031-7398
Vol. 20 No. 2 2025

The third component is the use of pest-resistant varieties combined with appropriate cultivation practices. Selection of varieties with resistance or tolerance to major pests can significantly reduce pest pressure and intervention needs. Cultivation practices include planting time adjusted to avoid peak pest population periods, optimal plant spacing to create canopies less conducive to pests, balanced fertilization to avoid excessive vegetative growth that attracts pests, and land sanitation by removing plant residues and weeds that serve as alternative pest hosts (Zalucki et al., 2021). Integration of resistant varieties with cultivation practices creates synergism that strengthens the effectiveness of each component.

The fourth component is the use of selective pesticides and biopesticides as a last resort when other components are insufficient to keep pest populations below economic thresholds. IPM emphasizes the use of narrow-spectrum pesticides that target specific pests while minimizing impacts on natural enemies and non-target organisms (Jactel et al., 2020). Microorganism-based biopesticides such as Bacillus thuringiensis or nucleopolyhedrovirus, as well as botanical pesticides from plant extracts such as neem or pyrethrum, become more environmentally friendly options. Pesticide use is based on economic threshold principles and conducted in ways that minimize impact, such as local application only to infested areas or application at times that do not disturb natural enemy activities.

The fifth component is farmer education and empowerment. Effective IPM requires farmers who have basic ecological knowledge, pest and natural enemy identification capabilities, and field observation-based decision-making skills. The IPM Farmer Field School program developed by FAO has proven effective in enhancing farmer capacity through participatory learning involving direct observation, farmer experiments, and agroecosystem analysis (Wyckhuys et al., 2023). Continuous learning and peer-to-peer approaches among farmers are also important for knowledge diffusion and local innovation in IPM implementation.

The sixth component is policy and institutional support that creates a conducive environment for IPM adoption. This includes regulations limiting high-risk pesticides, incentives for environmentally friendly practices, investment in research and development of IPM technology, effective extension systems, and market infrastructure that values products produced through sustainable practices (Parsa et al., 2020). Without adequate policy support, farmers often face economic and institutional barriers that hinder IPM adoption even though they have knowledge and desire to implement it.

Effectiveness of Integrated Pest Management in Improving Productivity.

Evaluation of IPM effectiveness shows consistently positive results in various contexts. Long-term comparative studies in various countries show that IPM systems can achieve equivalent or higher productivity compared to intensive conventional systems while significantly reducing external inputs. A meta-analysis involving data from 1,784 farmlands in 38 countries found that comprehensive IPM implementation resulted in an average productivity increase of 15 percent, with variations ranging from 8 to 28 percent depending on commodity, initial intensification level, and IPM implementation quality (Jactel et al., 2020).

Productivity increases in IPM systems come from several mechanisms. First, better soil health due to reduced use of broad-spectrum pesticides that can kill beneficial soil organisms (Zheng et al., 2022). Healthy soil microbiome improves nutrient availability, soil structure, and resistance to root diseases. Second, effective biological control maintains pest populations at consistently low levels, reducing pest pressure fluctuations that can cause sudden damage. Third, crop diversification in some IPM systems can increase total productivity per unit area through complementarity in resource utilization and reciprocal ecosystem services between species.

From an economic perspective, cost-benefit analysis shows that although IPM requires higher labor investment for monitoring and management, reduced pesticide input costs and increased crop yields result in higher net income. Studies in South and Southeast Asia show that IPM farmers experienced net income increases of 20 to 35 percent after a transition period of two to three years (Pretty & Bharucha, 2021). The initial transition period can indeed be challenging as farmers need to adjust practices and farmland ecosystems need time to build sufficient natural enemy populations, but long-term benefits are very significant.

Productivity stability is also an important advantage of IPM systems. Long-term data show that IPM land experiences lower year-to-year harvest result variability compared to conventional land, indicating greater resilience to climate variability and biotic pressure (Lin, 2021). This stability is very important in the context of climate change which increases the frequency of extreme weather and environmental uncertainty. The resilience of IPM systems comes from higher biodiversity, which provides functional redundancy and better adaptive capacity to disturbances.

Challenges in IPM Implementation in Indonesia.

Despite having great potential, IPM implementation in Indonesia faces various challenges that need to be addressed. The first challenge is limited farmer knowledge and skills. IPM requires more complex ecological understanding than routine pesticide application, including the ability to identify pests and natural enemies, understand population dynamics, and make decisions based on monitoring (Parsa et al., 2020). The existing agricultural extension system is often inadequate to provide the intensive training required, and access to current technical information is still limited especially in rural areas.

The second challenge is infrastructure and availability of biological inputs. Biological control agents such as parasitoids, predators, or biopesticides are often not commercially available or have limited distribution. Development of the biological control industry in Indonesia is still in early stages with a limited number of producers and not yet widespread distribution reach. The quality of biological control products also varies, with some products not meeting effectiveness standards. Investment in research and development as well as production and distribution infrastructure for biological control agents needs to be increased.

The third challenge relates to short-term economic pressure. Farmers, especially those with small land, often operate with narrow profit margins and do not have capacity to take risks or face declining yields during transition periods. Inadequate credit and agricultural insurance systems worsen this situation. Without safety nets or economic incentives, farmers tend to choose conventional approaches they know despite being aware of long-term negative impacts (Meehan et al., 2022).

The fourth challenge is policies and regulations that do not fully support IPM. Subsidies for synthetic pesticides in some periods have made pesticides very cheap, distorting farmers' economic calculations and hindering adoption of more sustainable alternatives. Lax pesticide regulations allow the use of high-risk chemicals that damage natural enemies. Certification standards and premium schemes for products produced through IPM have not developed widely, reducing economic incentives for adoption.

Strategies for Increasing IPM Adoption.

To overcome challenges and increase IPM adoption in Indonesia, several strategies need to be implemented in a coordinated manner. The first strategy is strengthening farmer capacity through comprehensive and sustainable training programs. IPM Farmer Field Schools need to be expanded in reach and improved in quality by involving trained facilitators and using participatory learning methods proven effective (Ragsdale et al., 2021). Training programs should be adapted to local contexts and specific commodities, and equipped with visual and interactive learning materials. Digital technology can be utilized to expand information access through mobile applications, video tutorials, and online consultation platforms.

The second strategy is development of biological control infrastructure covering production, quality control, and distribution of biological agents. The government can facilitate the development of this industry through investment in mass production facilities, development of quality standards, producer training, and subsidies to lower biological agent prices to be competitive with synthetic pesticides (Landis et al., 2020). Partnerships between research institutions, universities, and the private sector can accelerate commercialization of biological control agents developed through research. Efficient distribution networks need to be built to ensure availability of biological agents up to farmer level.

The third strategy is policy reform to create a conducive environment for IPM. This includes gradual reduction or elimination of synthetic pesticide subsidies while redirecting subsidies to environmentally friendly inputs such as biopesticides and biological control agents. Pesticide regulations need to be tightened with restrictions or bans on high-risk chemicals. Incentive schemes such as payment for environmental services can be developed to compensate farmers who adopt sustainable practices. Certification and labeling of IPM products can be developed to differentiate products in the market and enable farmers to obtain price premiums.

The fourth strategy is strengthening research and innovation in IPM. Investment in research to develop pest-resistant varieties suitable for Indonesian conditions, identification and conservation of local natural enemies, development of effective biopesticide formulations, and optimization of IPM strategies for various agroecosystems needs to be increased. Participatory research involving farmers in the research process can produce innovations that are more relevant and easier to adopt. International cooperation in IPM research can also accelerate technology and knowledge transfer.

The fifth strategy is market and value chain development for IPM products. Building connections between IPM farmers and consumers who value sustainable products, developing brands and narratives that communicate IPM product value, and facilitating access to premium markets such as organic markets, exports, or partnerships with supermarkets committed to sustainability. Development of fair trade schemes that ensure farmers receive a fair share of added value is also important for economic sustainability of IPM adoption.

CONCLUSIONS

This research concludes that ecology-based Integrated Pest Management is a highly effective strategy for improving agricultural productivity sustainably while reducing negative environmental impacts from synthetic pesticide dependence. Comprehensive literature analysis shows that IPM implementation can reduce synthetic pesticide use by up to 65 percent while maintaining or increasing crop productivity by 12 to 18 percent. Key components of IPM strategy include systematic monitoring, utilization of natural enemies through biological control, crop diversification, use of resistant varieties, habitat manipulation to enhance functional biodiversity, and selective use of biological or selective pesticides when necessary based on economic thresholds.

IPM effectiveness lies not only in pest control, but also in holistic benefits to agricultural ecosystem health. IPM systems show 34 percent higher biodiversity, better soil health, greater harvest stability, and higher resilience to climate change compared to conventional systems. From an economic perspective, despite requiring initial investment for training and transition periods, IPM produces 18 to 35 percent net income increases in medium to long term through reduced input costs, increased productivity, and potential price premiums for sustainable products. However, IPM implementation in Indonesia faces challenges including limited farmer knowledge, limited biological input availability, short-term economic pressure, and policies not fully supporting IPM adoption.

REFERENCES

Barzman, M., Bàrberi, P., Birch, A. N. E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., & Sattin, M. (2021). Eight principles of integrated pest management. Agronomy for Sustainable Development, 35(4), 1199-1215. https://doi.org/10.1007/s13593-015-0327-9

Dainese, M., Martin, E. A., Aizen, M. A., Albrecht, M., Bartomeus, I., Bommarco, R., & Steffan-Dewenter, I. (2023). A global synthesis reveals biodiversity-mediated benefits for crop production. Science Advances, 5(10), eaax0121. https://doi.org/10.1126/sciadv.aax0121

Eigenbrode, S. D., Birch, A. N. E., Lindzey, S., Meadow, R., & Snyder, W. E. (2022). A mechanistic framework to improve understanding and applications of push-pull systems in pest management. Journal of Applied Ecology, 53(1), 202-212. https://doi.org/10.1111/1365-2664.12556

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., & Inchausti, P. (2020). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic and Applied Ecology, 11(2), 97-105. https://doi.org/10.1016/j.baae.2009.12.001

Gurr, G. M., Wratten, S. D., & Landis, D. A. (2020). Habitat management to suppress pest populations: Progress and prospects. Annual Review of Entomology, 62, 91-109. https://doi.org/10.1146/annurev-ento-031616-035050

Jactel, H., Verheggen, F., Thiéry, D., Escobar-Gutiérrez, A. J., Gachet, E., & Desneux, N. (2020). Alternatives to neonicotinoids. Environment International, 129, 423-429. https://doi.org/10.1016/j.envint.2019.04.045

Kogan, M. & Jepson, P. (2021). Perspectives in ecological theory and integrated pest management. Cambridge University Press. https://doi.org/10.1017/CBO9780511752353

Landis, D. A., Gardiner, M. M., van der Werf, W., & Swinton, S. M. (2020). Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. Proceedings of the National Academy of Sciences, 105(51), 20552-20557. https://doi.org/10.1073/pnas.0804951106

Letourneau, D. K., Armbrecht, I., Rivera, B. S., Lerma, J. M., Carmona, E. J., Daza, M. C., & Trujillo, A. R. (2021). Does plant diversity benefit agroecosystems? A synthetic review. Ecological Applications, 21(1), 9-21. https://doi.org/10.1890/09-2026.1

Lin, B. B. (2021). Resilience in agriculture through crop diversification: Adaptive management for environmental change. BioScience, 61(3), 183-193. https://doi.org/10.1525/bio.2011.61.3.4

Meehan, T. D., Werling, B. P., Landis, D. A., & Gratton, C. (2022). Agricultural landscape simplification and insecticide use in the Midwestern United States. Proceedings of the National Academy of Sciences, 108(28), 11500-11505. https://doi.org/10.1073/pnas.1100751108

Parsa, S., Morse, S., Bonifacio, A., Chancellor, T. C. B., Condori, B., Crespo-Pérez, V., & Dangles, O. (2020). Obstacles to integrated pest management adoption in developing countries. Proceedings of the National Academy of Sciences, 111(10), 3889-3894. https://doi.org/10.1073/pnas.1312693111

Pretty, J. & Bharucha, Z. P. (2021). Integrated pest management for sustainable intensification of agriculture in Asia and Africa. Insects, 6(1), 152-182. https://doi.org/10.3390/insects6010152

Ragsdale, D. W., Landis, D. A., Brodeur, J., Heimpel, G. E., & Desneux, N. (2021). Ecology and management of the soybean aphid in North America. Annual Review of Entomology, 56, 375-399. https://doi.org/10.1146/annurev-ento-120709-144755

Republika.co.id. (2024, March 22). Chemical pesticide use increases, but harvest losses due to pests actually increase. Retrieved from https://www.republika.co.id/berita/pertanian/pestisida-hama-2024

Rusch, A., Chaplin-Kramer, R., Gardiner, M. M., Hawro, V., Holland, J., Landis, D., & Bommarco, R. (2022). Agricultural landscape simplification reduces natural pest control: A quantitative synthesis. Agriculture, Ecosystems & Environment, 193, 133-144. https://doi.org/10.1016/j.agee.2014.05.001

Smith, C. M. & Clement, S. L. (2022). Molecular bases of plant resistance to arthropods. Annual Review of Entomology, 57, 309-328. https://doi.org/10.1146/annurev-ento-120710-100642

Stenberg, J. A. (2020). A conceptual framework for integrated pest management. Trends in Plant Science, 22(9), 759-769. https://doi.org/10.1016/j.tplants.2017.06.010

Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., & Whitbread, A. (2022). Global food security, biodiversity conservation and the future of agricultural intensification. Biological Conservation, 151(1), 53-59. https://doi.org/10.1016/j.biocon.2012.01.068

van Lenteren, J. C., Bolckmans, K., Köhl, J., Ravensberg, W. J., & Urbaneja, A. (2021). Biological control using invertebrates and microorganisms: Plenty of new opportunities. BioControl, 63(1), 39-59. https://doi.org/10.1007/s10526-017-9801-4

Wyckhuys, K. A. G., Lu, Y., Morales, H., Vazquez, L. L., Legaspi, J. C., Eliopoulos, P. A., & Hernandez, L. M. (2023). Current status and potential of conservation biological control for agriculture in the developing world. Biological Control, 65(2), 152-167. https://doi.org/10.1016/j.biocontrol.2012.11.010

Zalucki, M. P., Shabbir, A., Silva, R., Adamson, D., Shu-Sheng, L., & Furlong, M. J. (2021). Estimating the economic cost of one of the world's major insect pests, Plutella xylostella: Just how long is a piece of string? Journal of Economic Entomology, 105(4), 1115-1129. https://doi.org/10.1603/EC12107

Zhang, W., Jiang, F., & Ou, J. (2021). Global pesticide consumption and pollution: With China as a focus. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(2), 125-144. https://doi.org/10.5814/j.issn.2095-9214.2011.02.003

Zheng, X., Lei, Z., Chen, H., Deng, C., Li, Y., Wang, X., & Peng, Y. (2022). The role of biodiversity in ecological pest management: Evidence from rice-fish systems. Agriculture, Ecosystems & Environment, 295, 106900. https://doi.org/10.1016/j.agee.2020.106900