ISBN: 978-81-978152-3-2

5. Integrated Pest Management for Sustainable Agriculture Principles and Practices

Ishika Wijesundara

W.M.S.I
Department of Crop Science Faculty of Agriculture,
University of Ruhuna, Matara, Sri Lanka.

Abstract:

The emerging paradigm in crop protection, Integrated Pest Management (IPM) for sustainable agriculture emphasizes on the incorporation of different principles into pest management while ensuring high productivity and profitable harvests without causing harm to the environment. IPM advocates the integration of diverse pest management strategies, including cultural, physical, mechanical, biological, and chemical methods to prevent pests from reaching damaging levels. By promoting practices that minimize chemical reliance and encourage ecological balance, IPM emerges as a vital approach to sustainable crop protection. This chapter provides a comprehensive overview of the principles and practices of IPM, demonstrating how they contribute to achieve sustainable agricultural goals while ensuring high yields and profitability without degrading the environment.

Keywords:

Crop production, Crop protection, Integrated pest management, Sustainable agriculture.

5.1. Introduction:

At the beginning, farming was largely organic with traditional methods that naturally aligned with ecological principles. However, the advent of the Green Revolution in the mid-20th century brought high-input industrial agriculture, based on the wide use of synthetic fertilizers, pesticides, high yielding varieties and monoculture cropping systems (Abrol & Shankar, 2012; Aselage & Johnson, 2008). While this strategy nearly tripled food production, at a huge cost: it also led to negative consequences such as soil degradation, water pollution, loss of biodiversity, and increased emissions of greenhouse gases (Bentley et al., 1995; Reddy, 2017). In the second half of the 20th century, concern for these problems started giving way to the concept of sustainable agriculture. Pioneers in the movement advocated for a return to practices that work in harmony with nature, such as crop rotation, organic farming, and integrated pest management (IPM) (Reddy, 2017). IPM is a holistic approach of pest management, integrating different methods of pest control to achieve environmental stewardship, economic profitability, and social equity (Sullivan, 2003) at the same time ensuring the long-term viability of agricultural systems.

It emphasizes the conservation and efficient use of natural resources like soil, water, and biodiversity, aiming to reduce environmental impact while maintaining productivity (Aselage & Johnson, 2008).

5.1.1 Historical Perspective and Evolution of Integrated Pest Management (IPM):

The concept of IPM is not new; its origins traced back to ancient agricultural practices that integrated various pest control methods in a synergistic manner. The terms "Integrated Pest Management" and "IPM" first entered the lexicon in the early 1970s (Abrol & Shankar, 2012; Angon et al., 2023; Ha, 2014). Overuse of insecticides resulted in insect resistant, resurgence of pests after treatment and occurrence of secondary pests (Radcliffe et al., 2009) while the natural enemies that had been keeping them in check were killed by insecticides (Ha, 2014). "Integrated control" was developed in the 1950s (Baker et al., 2020) emphasizing use of selective insecticides so that natural enemies were conserved in the system. This integration of control techniques was expanded in later 1970s to include other management options such as resistant crop varieties, crop rotation and other tactics. This new approach was termed as Integrated Pest Management or IPM (Ehler, 2006).

5.1.2 Definitions of Integrated Pest Management (IPM):

Integrated Pest Management (IPM) has been known for some decades but is often used and understood in different ways by different people. The FAO definition for IPM is as follows.

"Integrated Pest Management (IPM) means the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human and animal health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms".

Radcliffe et al. (2009) defined IPM as applied pest control, which combines and integrates biological and chemical control and employed the use of economic thresholds to determine when chemical control should be utilized to prevent pests from reaching the economic injury level.

IPM is based on a principle of optimum rather than maximum pest control, but tactics include managing nutrients for optimal plant health and improving soil health such as increasing diversity and abundance of beneficial organisms in the soil (Baker et al., 2020). IPM is a dynamic process that applies an ecological systems perspective and encourages the producer and users think through and employ the entire spectrum of the best pest control options available, given economic, environment and social considerations.

Therefore, management programmes with the regular application of chemicals are not encouraged in IPM. Instead, priority should be given to prevention and alternative control tactics. It also involves measures including prevention, monitoring, forecasting, early diagnosis, which help, slow the development of pest populations.

5.1.3 Importance of Integrated Pest Management (IPM):

The growing population in the world significantly threatens food production sustainably, increasing demands for agriculture products. In the quest to restrain these pests, the intensive use of chemical pesticides is often employed within modern agricultural practices, but these approaches have serious detrimental effects on non-target organisms, human beings and the environment, in addition to the fact that they increase pesticide resistance (Radcliffe et al., 2009). Because of this, it is now evident that new and more sustainable farming techniques have to be established for maintaining soil fertility, using non-renewable resources, and adapting to the environment and primordial diversity (Aselage & Johnson, 2008; Faroque et al., 2013; Kluson, n.d.). Integrated Pest Management (IPM) emerges as a pivotal strategy in addressing these challenges, offering a balanced and sustainable approach to pest control. IPM is thus anchored in ecological principles and focuses on a varied range of practices and techniques in order to maintain pest populations within acceptable limits without adverse impacts on the environment and human health (Fiant, 2023). This holistic approach incorporates biological, cultural, physical, and chemical methods in a coordinated manner, striving to achieve long-term pest suppression (Dwivedi et al., n.d.).

5.2 Principles of Integrated Pest Management:

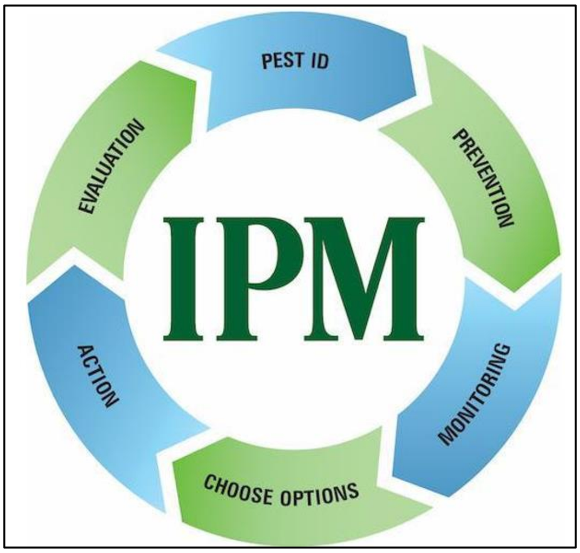

Figure 5.1: Principles of Integrated Pest Management

Prevention and Suppression:

In any IPM programme, prevention is the main strategy for controlling pest. Implementing preventative measures inherently reduces the risk of incidence, and suppressing harmful organisms reduces the possibility of a single species becoming dominant and significantly influencing a cropping system. Crop rotation, varietal choice, use of certified seeds, maintaining field hygiene, cultivation practices, cultivating beneficial species are most effective strategies for preventing pest outbreaks (Barzman et al., 2015; O'Reilly, n.d.).

Identify Pests:

Identification of pest, its various life stages and its effects are considered as the key components of any integrated pest management plan. An accurate identification of pests helps to determine their pest status, population dynamics and effective control measures (Barzman et al., 2015). However, even for any qualified and expert entomologist, accurate identification of dominant pest species at the field is a complex and difficult task. Continuous and constant efforts to recognize the prevailing pest species makes correct identification of pests of a particular crop comparatively easier (Arif et al., 2017).

Monitor Pest Population Levels:

Monitoring pest is the fundamental tool in IPM for making management decision. Monitoring reveals changes in insect pest distribution and abundance, outbreak patterns and life cycles, and the impact of ecological, climatological and biological factors on the pest movements (Dara, 2019). Monitoring assists in identifying the rate of development of insecticide resistance of important insect pests (Barzman et al., 2015). Effective monitoring includes regular farm visits and scouting, recording information on the incidence of damage to crops alongside recording the number of insect pests and beneficial species

Determine Acceptable Injury Level:

Economic decision rules are fundamental to the effective implementation of Integrated Pest Management (IPM) as they guide the timing and necessity of pest control interventions to optimize economic outcomes. Central to these decision rules are the concepts of economic injury level (EIL) and economic threshold (ET) (Radcliffe et al., 2009). The EIL represents the lowest population density of pests at which the economic losses caused by pests equal the cost of control measures. It serves as a critical point where the cost-benefit analysis justifies the need for pest management actions. Going beyond this level would mean that the economic damage caused by pests outweighs the costs involved in controlling them leading to financial loss (Felsot & Racke, 2006; Radcliffe et al., 2009). The ET, often set below the EIL, is the pest population density at which action must be taken to prevent the population from reaching the EIL. By acting at the ET, IPM practitioners aim to control pest populations before they reach levels where they would cause significant economic damage, thereby avoiding unnecessary costs and protecting crop yields. These economic decision rules are designed to ensure that pest control is both economically viable and environmentally sustainable, reducing the reliance on broad-spectrum pesticides and promoting more targeted, cost-effective interventions.

Develop and implement an IPM program:

Pest levels can be regulated in a number of different ways. Achieving a sustainable level of pest management requires a broad strategy that encompasses multiple methods. However, selection of an appropriate control practice or highly compatible control measures is a key to success of any pest management program. Following principles and criteria should be followed while selecting single or set of control practices;

- Feasibility of available resources
- Flexibility in cropping program
- Economic feasibility

Use of pesticides at required levels:

Reducing reliance on pesticides is the goal of IPM. When alternative control strategies and prevention do not produce satisfactory results on their own, use of pesticides come as last resort. Selecting the best insecticides for pest management that have minimal impacts on beneficial organisms can be challenging. Numerous databases and ranking systems that take into account pesticide toxicities to non-target species as well as other variables including human toxicity and environmental contamination potential have been established to help with this effort. (Peshin & Dhawan, 2009). However, reducing doses, application frequency, and resorting to partial application of pesticides contribute to the IPM goal of reducing or minimizing risks to human health and the environment (Barzman et al., 2015).

Evaluate program:

This principle encourages farmers to assess the soundness of the crop protection measures they adopt, and this is an important aspect of sound management. Keeping detailed records of pests and numbers observed, type and dosage of chemicals used and environmental factors such as the weather helps study the effectiveness of plant protection measures.

5.2.1 Key Components of Integrated Pest Management:

Integrated Pest Management (IPM) is a comprehensive approach to pest control that integrates multiple strategies to manage pests effectively while minimizing environmental impact. Key components of IPM include cultural control, physical and mechanical control, biological control and chemical control, which uses pesticides as a last resort, applying them in a targeted and judicious manner to minimize harm to non-target organisms and the environment.

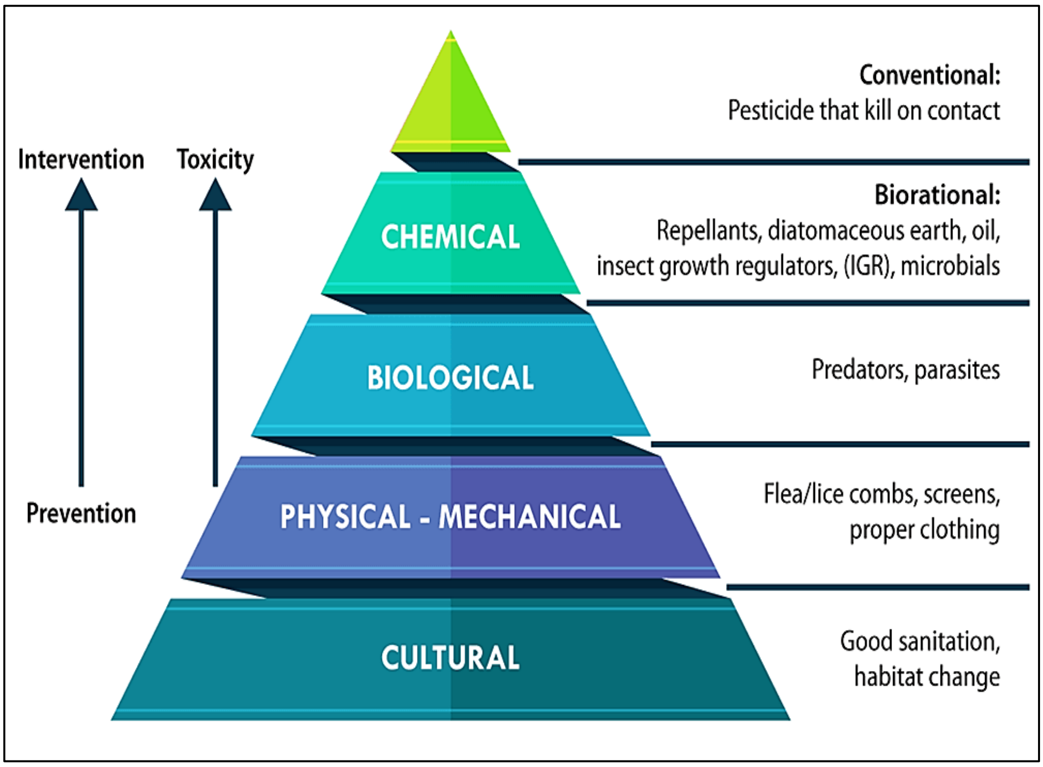

Figure 5.2: Key Components of Integrated Pest Management for Sustainable Agriculture

Cultural Control:

Cultural control in integrated management explore and enhance synergies of ecological processes that limit pest invasion and population growth in an agro ecosystem (Bajwa & Kogan, 2004). Use of cultural practices for pest control is one of the oldest and most effective pest management tactics. Cultural IPM methods are more effective when crops are healthy. Cultural control tactics are agronomic practices primarily aimed at the prevention and reduction of pest outbreaks by increasing pest mortality or reducing its rates of increase, dispersal and overall damage potential (Bentley et al., 1995). IPM cultural methods include the following field management techniques.

- Selection of good planting material
- Soil treatment/ploughing/tillage
- Selection of suitable plants with resistance and tolerance
- Crop rotation

- Intercropping, strip cropping, push-pull farming
- Choice of planting dates
- Pruning, thinning and proper spacing
- Weed control
- Planting of trap plants

Biological Control:

Biological control is a form of ecologically based pest management that uses a kind of organism by introductions, conservation, or augmentation to maintain pest populations below economically injurious levels (Peshin & Dhawan, 2009; Rao et al., n.d.). Natural enemies include parasitoids, predators, entomopathogenic nematodes, pathogens, competing microorganisms with or hyperparasites of plant pathogens, competitors for resources and organisms producing toxins, termed antibiosis or allelopathy (Baker et al., 2020; Fiant, 2023).

Bio pesticides also known as biological pesticides are certain types of pesticides derived from such materials as animals, bacteria, and certain minerals (Rao et al., n.d.). These pesticides play a crucial role in minimizing the risk associated with chemical pesticides. Key features of Bio-pesticides include:

- Have a narrow target range of pests and a very specific mode of action
- Are slow acting
- Have relatively critical application times
- Reduce pest population rather than eradicating them completely
- Have limited persistence in the field and short shelf life
- Are generally safer to both humans and the environment compared to conventional pesticides
- Present no residue problems

The role of biological control in IPM is to cause a minimum imbalance in ecosystems by mimicking nature. Bio control in integrated management is similar to natural processes, yet natural control occurs without human intervention (Baker et al., 2020; Dwivedi et al., 2024.; Sullivan, 2003).

Physical and Mechanical Control:

Physical and mechanical methods are non-chemical strategies that either directly or indirectly eliminate pests or alter the environment to prevent their entry, dispersal, survival and reproduction (Dwivedi et al., 2024). Physical-mechanical control measures may include environmental manipulation like temperature, relative humidity, control atmosphere

(Angon et al., 2023). Many times, mechanical and physical methods require considerable extra equipment, materials and labour. Hence, they may only be economical in certain situations. For controlling field pests, these methods are generally less effective. However, in a storage environment, many of the physical techniques are highly effective and hold significant potential for use in an IPM system. Mechanical methods include the following techniques:

- Hand picking
- Use of screens/nets/barriers
- Use of mechanical traps (pheromone trap, wing trap, water pan, sticky trap, methyl eugenol trap)
- Pest repelling devices
- Use of environmental manipulation (e.g., temperature, light)

Chemical Control:

Chemical control in Integrated Pest Management is a strategy that involves the use of pesticides or insecticides to manage pest populations. The high degree of efficacy, good availability, and generally low cost make chemical control an attractive option for pest control (Felsot & Racke, 2006). However, in IPM, chemical control is used as a last resort only after all other methods such as cultural, biological, and mechanical controls have been considered and implemented and is integrated with other pest management practices to minimize risks to human health, beneficial organisms, and the environment. In such cases, the pesticides used had to have certain characteristics and usually attempt to obtain satisfactory control using one of the "biorational" pesticides, which are fairly pest-specific and usually non-persistent, causing a minimal amount of harm to beneficial organisms (Fiant, n.d.; Sullivan, 2003). Selective insecticides should only be applied when the ratio of pests to natural enemies was unfavorable for adequate crop protection. Pesticides must degrade rapidly and not leave residues that would expose biological control agents once the pest population was knocked down (Felsot & Racke, 2006).

Successful and efficient pesticide application requires a proper understanding of the individual mechanisms and modes of action. The effectiveness of chemical control in IPM is based on its ability to provide rapid pest suppression, flexibility to target a range of pest issues, and be compatible with other IPM methods.

5.3 Role of IPM in Achieving Sustainable Agriculture:

Integrated Pest Management is a tool based on the principle of eco-friendly agriculture, while it takes a holistic approach to pest management, giving due consideration to sustainable development and environmental safeguard. IPM substantially contributes to improvement in farm productivity and availability of food by reducing crop loss both before and after harvest. This certainly shows that the reduction in loss will directly turn into an increase in yield and more regular supplies of food, which are important for supply to meet growing demand.

One of the main advantages of IPM is the reduction of pesticide residues because of the least application of chemical pesticides (Ehler, 2006), IPM helps ensure that the residues in food, feed, fiber, and the surrounding environment are kept at a minimum. This is particularly important for safety of food and water, as excess residues of pesticides bring about health problems to consumers and contaminate water sources. Furthermore, the reduced reliance on chemical inputs means that farmers are less exposed to potentially harmful substances, thereby improving occupational health and safety in agricultural communities (Pretty & Bharucha, 2015).

The key of Integrated Pest Management is its capacity to maintain crop ecosystem balance while enhancing ecosystem benefits. By providing sustainable pest management while preserving pollinators and other vital ecosystem services, IPM improves already existing ecosystem services (Datta et al., 2023).

It preserves the foundation of natural resources, such as biodiversity, water, and soil all of which are necessary for sustainable agriculture. Crop health and productivity are largely dependent on healthy soils that are abundant in organic matter and rich with soil microorganisms. By fostering these conditions, IPM promotes soil fertility and structure, leading to better water retention and reduced erosion (He et al., 2019). Moreover, the emphasis on biodiversity ensures a robust and resilient ecosystem that can better withstand pest outbreaks and environmental stresses.

Economically, IPM has several benefits for farmers. By reducing the need for chemical pesticides, production costs are lowered, increasing the economic viability of farming operations (Kabir & Rainis, 2013). Additionally, crops grown under IPM practices are often of higher quality, with fewer pesticide residues. Because these superior commodities can fetch higher prices at the market, farmer profitability will increase (Smithers, 1993). This economic incentive encourages more farmers to adopt IPM practices, creating a positive feedback loop that further promotes sustainable agriculture.

Beyond the economic and environmental benefits, IPM also strengthens farmer knowledge and stewardship. By promoting an understanding of ecosystem functioning and pest dynamics, IPM empowers farmers to make informed decisions tailored to their local context. This knowledge transfer is crucial for the long-term sustainability of agricultural practices, as it encourages continuous learning and adaptation. Farmers become stewards of the land, implementing practices that not only improve their yields but also protect the environment for future generations.

5.4 Challenges in Implementing Integrated Pest Management:

- Lack of awareness, knowledge and training on IPM practices
- Inadequate extension services and limited access to information
- Economic constraints
- Pest resistance and resurgence
- Changing climatic conditions
- Regulatory and policy barriers
- Complexity and labour intensity
- Resistance to adopting IPM practices

5.5 Conclusion:

Integrated Pest Management offers a sustainable approach to agriculture, balancing the need for high yields with environmental preservation. By integrating cultural, biological, mechanical, and chemical methods, IPM reduces reliance on harmful pesticides, fosters biodiversity, and improves soil health to achieve long-term pest control, ensuring sustainable productivity. As agriculture faces increasing challenges, IPM emerges as a critical strategy for maintaining food security and environmental integrity, making it indispensable for the future of sustainable farming.

5.6 References:

1. Abrol, D. P., & Shankar, U. (Eds.). (2012). Integrated pest management: Principles and practice. CABI.
2. Angon, P. B., Mondal, S., Jahan, I., Datto, M., Antu, U. B., Ayshi, F. J., & Islam, Md. S. (2023). Integrated Pest Management (IPM) in Agriculture and Its Role in Maintaining Ecological Balance and Biodiversity. Advances in Agriculture, 2023, 1–19. https://doi.org/10.1155/2023/5546373
3. Arif, M. J., Gogi, M. D., Nawaz, A., & Sarfraz, R. M. (2017). Principles of Insect Pests Management.
4. Aselage, J., & Johnson, D. T. (2008). From IPM to organic and sustainable agriculture. In E. B. Radcliffe, W. D. Hutchison, & R. E. Cancelado (Eds.), Integrated Pest Management (1st ed., pp. 489–505). Cambridge University Press. https://doi.org/10.1017/CBO9780511626463.040
5. Bajwa, W. I., & Kogan, M. (2004). Cultural practices: Springboard to IPM. In O. Koul, G. S. Dhaliwal, & G. W. Cuperus (Eds.), Integrated pest management: Potential, constraints and challenges (1st ed., pp. 21–38). CABI Publishing. https://doi.org/10.1079/9780851996868.0021

6. Baker, B. P., Green, T. A., & Loker, A. J. (2020). Biological control and integrated pest management in organic and conventional systems. Biological Control, 140, 104095. https://doi.org/10.1016/j.biocontrol.2019.104095
7. Barzman, M., Bàrberi, P., Birch, A. N. E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., Hommel, B., Jensen, J. E., Kiss, J., Kudsk, P., Lamichhane, J. R., Messéan, A., Moonen, A.-C., Ratnadass, A., Ricci, P., Sarah, J.-L., & Sattin, M. (2015). Eight principles of integrated pest management. Agronomy for Sustainable Development, 35(4), 1199–1215. https://doi.org/10.1007/s13593-015-0327-9
8. Bentley, J. W., Castaño-Zapata, J., & Andrews, K. L. (1995). 13 World integrated pathogen and pest management and sustainable agriculture in the developing world. In Advances in Plant Pathology (Vol. 11, pp. 249–276). Elsevier. https://doi.org/10.1016/S0736-4539(06)80015-2
9. Dara, S. K. (2019). The New Integrated Pest Management Paradigm for the Modern Age. Journal of Integrated Pest Management, 10(1). https://doi.org/10.1093/jipm/pmz010
10. Datta, S., Hamim, I., Jaiswal, D. K., & Sungthong, R. (2023). Sustainable agriculture. BMC Plant Biology, 23(1), 588, s12870-023-04626–04629. https://doi.org/10.1186/s12870-023-04626-9
11. Dwivedi, E. P., Mishra, E. R., & Rani, V. (2024). Integrated Pest Management and Sustainable Agriculture: A Review.
12. Ehler, L. E. (2006). Integrated pest management (IPM): Definition, historical development and implementation, and the other IPM. Pest Management Science, 62(9), 787–789. https://doi.org/10.1002/ps.1247
13. Faroque, M., Kashem, M., & Bilkis, S. (2013). Sustainable Agriculture: A Challenge in Bangladesh. International Journal of Agricultural Research, Innovation and Technology, 1(1–2), 1–8. https://doi.org/10.3329/ijarit.v1i1-2.13922
14. Felsot, A. S., & Racke, K. D. (Eds.). (2006). Crop Protection Products for Organic Agriculture: Environmental, Health, and Efficacy Assessment (Vol. 947). American Chemical Society. https://doi.org/10.1021/bk-2007-0947
15. Fiant, D. (2023). Effective pest management strategies for sustainable agriculture. J Agric Sci Bot. 7(3):181
16. Ha, T. M. (n.d.). A Review on the Development of Integrated Pest Management and Its Integration in Modern Agriculture. 02(04).
17. He, H., Liu, L., Munir, S., Bashir, N. H., Wang, Y., Yang, J., & Li, C. (2019). Crop diversity and pest management in sustainable agriculture. Journal of Integrative Agriculture, 18(9), 1945–1952. https://doi.org/10.1016/S2095-3119(19)62689-4
18. Integrated pest management of major pests and diseases in eastern Europe and the Caucasu, Food and Agriculture Organization of the United Nations Budapest, 2017.
19. Kabir, M. H., & Rainis, R. (2013). Integrated pest management farming in Bangladesh: Present scenario and future prospect. 9.
20. Kluson, R. A. (n.d.). * Sustainable Agriculture * Definitions and Concepts.
21. O'Reilly, D. (n.d.). Integrated pest management guide.

22. Peshin, R., & Dhawan, A. K. (Eds.). (2009). Integrated Pest Management: Innovation-Development Process. Springer Netherlands. https://doi.org/10.1007/978-1-4020-8992-3
23. Pretty, J., & Bharucha, Z. (2015). Integrated Pest Management for Sustainable Intensification of Agriculture in Asia and Africa. Insects, 6(1), 152–182. https://doi.org/10.3390/insects6010152
24. Radcliffe, E. B., Hutchison, W. D., & Cancelado, R. E. (Eds.). (2009). Integrated pest management: Concepts, tactics, strategies and case studies. Cambridge University Press.
25. Rao, D. V. P., Veeraraghavaiah, D. R., Hemalatha, D. S., & Joseph, D. B. (n.d.). Farming Systems and Sustainable Agriculture.
26. Reddy, P. P. (2017). Agro-ecological Approaches to Pest Management for Sustainable Agriculture. Springer Singapore. https://doi.org/10.1007/978-981-10-4325-3
27. Smithers, J. (1993). Sustainable Agriculture: Interpretations, Analyses and Prospects. SUSTAINABLE AGRICULTURE. Canadian Journal of Regional Science. Pp 499-524.
28. Sullivan, P. (2003). Applying the Principles of Sustainable Farming.