



Precision Entomology: The Next Frontier in Crop Protection

**Kritika Saklani¹, Dr Avinash Chauhan², Amol S. Ingle³,
Anu Chaudhary⁴,
Anup Kumar Verma⁵**

¹Ph.D Scholar, Department of Entomology, Punjab Agricultural University, Ludhiana.

²Scientist, Department of Entomology, School of Agricultural Sciences, Nagaland University Medziphema Chumoukedima 797106, Nagaland.

³Ph.D Scholar, Department of Entomology, CP College of Agriculture SDAU SARDARKRUSHINAGAR.

⁴Research Scholar, Department of Zoology, Acharya Narendra Dev Kisan P.G. College, Babhnan, Gonda, Uttar Pradesh, India.

⁵Research Scholar, Department of Zoology, Acharya Narendra Dev Kisan P.G. College, Babhnan, Gonda, Uttar Pradesh, India.



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*Corresponding Author
Kritika Saklani*

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INTRODUCTION

Insects pests remain a major threat to world agricultural production, with the potential to cause significant crop loss in both quantity and quality. Integrated pest management has long been based upon field scouting knowledge and calendar pesticide applications. But all of these methods are frequently time-consuming and expensive, and they may raise environmental issues, such as pesticide resistance, loss of biodiversity, and contamination of water or soil. With the advent of digital agriculture, a novel approach of Precision Entomology (PE) has been introduced, where entomological expertise is integrated with state-of-the-art technologies such as Artificial Intelligence (AI), Unmanned Aerial Vehicles (UAVs), remote sensing, Geographic Information Systems (GIS), Internet of Things (IoT), and big data analytics. Precision entomology exploits unprecedented monitoring, forecasting, and management of insect pests while balancing sustainable and economically sound crop protection.

What is Precision Entomology

Precision entomology is a subdiscipline of precision agriculture that deals with the site-scale monitoring and management of insect pests. In contrast to uniform treatment of an entire field, precision entomology dictates pest infestations and allows for interventions at the right place, right time, and right intensity. The idea rests on the fact that pest populations are seldom evenly spread in agricultural fields. By monitoring space and time dynamics of pest outbreaks, farmers are empowered to make sound decisions on (and possibly reduce) pesticide use without compromising effective pest control.

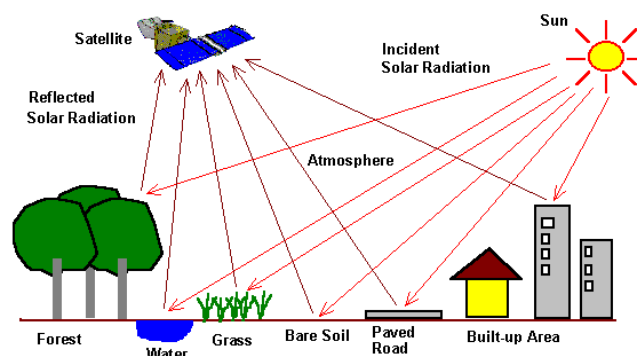
Technologies Driving Precision Entomology

1. Remote Sensing and Imaging

Technologies

Remote sensing led to a revolution in pest monitoring with the result that crop condition could be monitored quickly and over large areas. They achieve this by using multispectral, hyperspectral, thermal and RGB sensors to

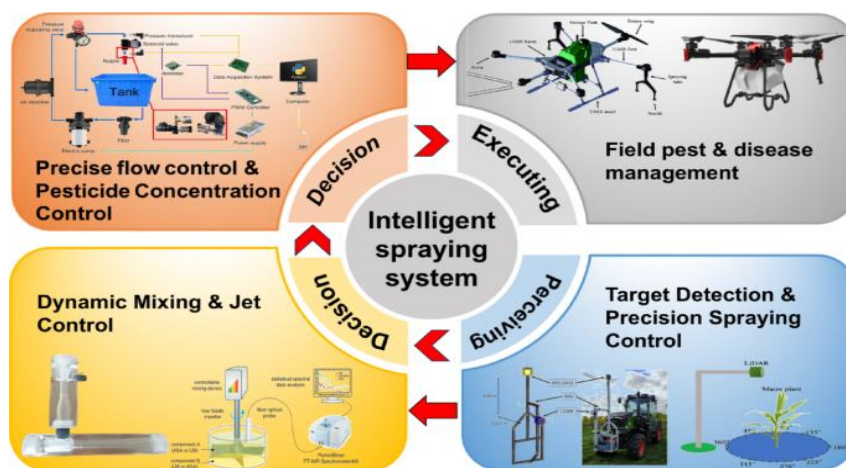
identify the early physiological changes induced by insect feeding prior to the onset of visible symptoms. Canopy temperature, chlorophyll content, and vegetation indices can be used to detect areas affected by pests and they can be applied for timely and site-specific actions to reduce crop loss and to stop the dissemination of pest outbreaks.



2. Drone-Based Pest Monitoring

Unmanned Aerial Vehicles (UAVs), popularly known as drones, are now an essential instrument in precision pest management.

Drones are fitted with high definition cameras and sophisticated sensors that can collect field data in real time to produce pest distribution maps.



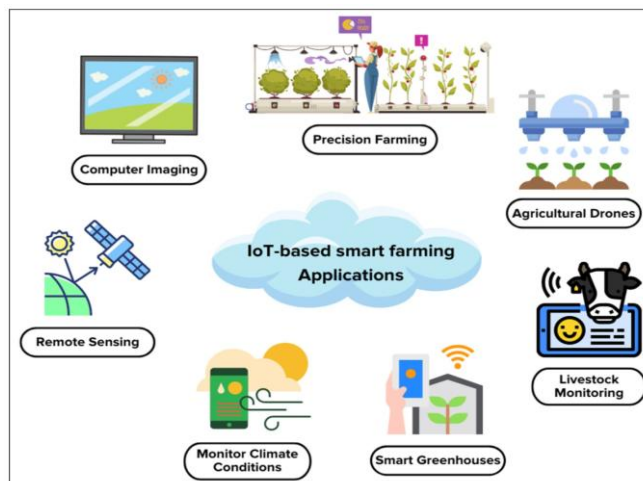
3. Artificial Intelligence and Machine Learning

AI is now becoming the new game changer in crop protection. Machine learning algorithms can process field images by the thousands to detect pest species, assess population density, and forecast infestation risks.

and decision support. Smart traps equipped with sensors are capable of automatically acquiring insect images, observing and counting pest populations, and sending real-time data to cloud-based platforms for processing. They allow pest population dynamics to be monitored with accuracy, and control can be implemented in time, avoiding the infestation to grow and cause economic damage.

4. Internet of Things (IoT) and Smart Traps

IoT has led to the creation of intelligent insects monitoring systems to improve pest monitoring



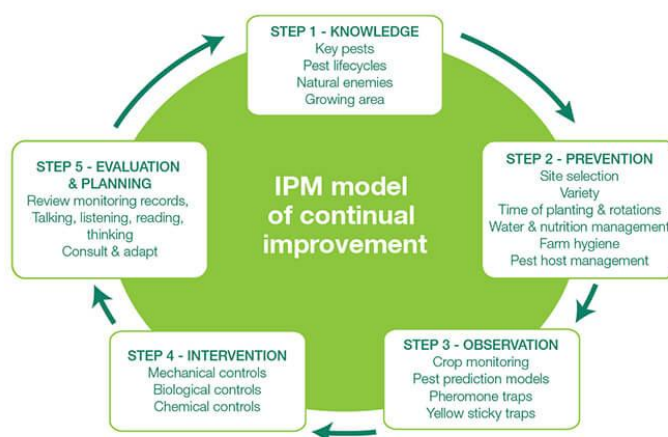
5. Geographic Information Systems (GIS)

GIS technology has been used in pest population mapping and is essential to the study of pest spatial distribution. GIS-based models can predict pest outbreaks and advise site-specific actions when pest information is combined with environmental factors (e.g. temperature, humidity, soil type) and crop growth stages, in a manner similar to the RI model.

Precision Entomology and Integrated Pest Management

Precision entomology is a valuable

complement to Integrated Pest Management (IPM), increasing the efficacy of traditional pest control methods by means of data-led decisions. It enhances pest monitoring, allows for accurate calculation of economic thresholds, reduces excessive pesticide use, preserves natural enemies, minimizes environmental side effects, and raise farmer's profit. Precision technologies allow specific, timely interventions, enabling farmers to apply pesticides only where and when needed, improving pesticide use efficiency without compromising pest control or sustainable crop protection.



Benefits of Precision Entomology Economic Benefits

Precision entomology also has the potential to decrease costs for producers and increase efficiency by reducing the amount of

pesticides applied, and ultimately increasing crop yields and farm profitability. Its data-centric strategy allows for the optimal use of resources, which brings about higher yields and a more sustainable agricultural production.

Environmental Benefits

Precision entomology contributes to environmental good of precision pesticide through preventing the contamination of the environment, protecting benefits creatures and normal foe of the pest, postponing the high level of pesticide opposition on pest gatherings and supporting the soundness of biological framework and its difference, which along these lines backs away sustainable and friendly toward natural pesticide protection of crops.

Social Benefits

Precision entomology also indirectly supports social welfare by increasing farmer safety and decreasing exposure to harmful chemicals due to appropriate application of pesticides, while strengthening food safety and quality by limiting pesticide residues on food products.

Technological Benefits

Precision entomology has the potential to provide significant technological benefits, such as allowing pests to be monitored in real time and decisions made more quickly and accurately, enabling better use of resources with site-specific management actions, and endorsing data-driven farm management. These solutions enable the farmers to fine-tune their pest management practices, increase operational efficiency and work towards more sustainable and productive agricultures.

Challenges and Limitations

Although precision entomology has far-reaching potential, its application is limited by several challenges such as high upfront costs, low levels of technical expertise of farmers, complexities in data management, the requirement for stable internet connection, airspace regulations concerning drone operations, and the absence of region-specific models for pest prediction. These constraints are especially relevant for smallholder farmers in the developing world,

where financial and infrastructural barriers may prevent these best-practice pest management technologies from being taken up.

Future Prospects

New developments in artificial intelligence, robotics, cloud computing, and autonomous systems are shaping the future of precision entomology. Novel technologies like autonomous scouting robots, AI- based pest forecasting platforms, digital surveillance networks, swarm drones, real-time decision support systems, and integration with climate-smart agriculture are poised to transform the pest management. In one concept being pursued by scientists, sensors, drones and AI seamlessly work together within agricultural ecosystems to constantly monitor crop conditions, delivering real-time, data-driven advice, with the potential to increase sustainability, lessen reliance on chemical pesticides, and bolster the ability of farming systems to adapt to an ever-changing climate.

CONCLUSION

Precision entomology is a transformative development that shifts focus from reactive pest management to a proactive and data-driven approach for crop protection. Through the fusion of entomological knowledge and state-of-the-art digital technologies, farmers can gain a more precise understanding of pest populations, perform control measures more efficiently and with reduced environmental impact. With agriculture shifting towards greater sustainability and resource-use efficiency, precision entomology will likely be the next innovation field in crop protection. If broadly implemented, it could transform pest management, improve food security, and foster resilient agricultural systems for future generations.