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INTEGRATED PEST MANAGEMENT (IPM) 2.0: NEW TECHNOLOGIES AND TECHNIQUES

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Integrated Pest Management (IPM) is a comprehensive approach to pest control that combines multiple strategies to manage pest populations in an environmentally and economically sustainable manner. IPM 2.0 refers to the evolution of traditional IPM practices, incorporating cutting-edge technologies and innovative techniques to enhance effectiveness and adaptability in modern agriculture. It is an advanced approach that combines traditional control methods with innovative technologies and techniques to manage pests effectively. This modernized approach incorporates artificial intelligence, precision agriculture, and data analytics to optimize pest control strategies. IPM 2.0 also emphasizes sharing knowledge, best practices, and decision-making tools among farmers, researchers, and policymakers. The goal is to minimize environmental impact while ensuring food security and sustainable agricultural practices. By adopting IPM 2.0, farmers can achieve more efficient and effective pest management, leading to increased crop yields and reduced reliance on chemical pesticides.

Advancement of IPM 2.0

Smart Pest Monitoring Systems

- **Sensors and IoT (Internet of Things):** Modern pest management often utilizes smart sensors and IoT devices to monitor pest activity in real-time. These sensors can detect changes in environmental conditions, pest populations, and crop health, providing farmers with data-driven insights. Wang *et al.* (2013) set up a large number of environmental sensors in an apple orchard for the purpose of recording the status of the orchard. The YOLOv3 model was used to identify anthrax on the surface of the apples and analyze the health of the apples.

- **Automated Traps:** New traps equipped with cameras and sensors can capture images of pests and transmit data for analysis. This allows for precise identification and monitoring of pest populations. Goldshtein *et al.* (2017) state that imaging the trapped insects and detecting insect entry through a passage are two approaches that dominate in the development of automatic pest monitoring devices.

Drones and Aerial Imaging

- **Precision Mapping:** Drones equipped with high-resolution cameras and multispectral sensors can create detailed maps of fields. These maps help identify pest hotspots, crop health variations, and areas needing attention. Martin and Moisan (2008) used the Single Seed Descent (SSD) method to identify and analyze the pests in the images. Once the SSD model has been trained, the pests identification accuracy reaches 84% and the pest species classification accuracy reaches 86%.
- **Targeted Application:** Drones can be used for targeted pesticide or biological control agent application, minimizing the use of chemicals and reducing environmental impact.

Artificial Intelligence and Machine Learning

- **Predictive Analytics:** AI and machine learning algorithms analyze historical pest data, weather patterns, and crop conditions to predict pest outbreaks. Miranda *et al.* (2014) used the VGG19 method for image feature extraction and recognition in the detection of 24 types of pests from crop images. This helps farmers anticipate and prepare for pest issues before they become severe.
- **Decision Support Systems:** AI-driven decision support tools provide recommendations on the best pest management strategies based on real-time data and predictive models.

Biological Control Innovations

- **Enhanced Beneficial Organisms:** Advances in biotechnology have led to the development of more effective and resilient beneficial insects, fungi, and bacteria that can be used to control pest populations.
- **Microbial Biopesticides:** New strains of microbial biopesticides are being developed to target specific pests more effectively while being safe for humans, animals, and beneficial insects.

Genetic Tools and Techniques

- **CRISPR and Gene Editing:** Gene editing technologies like CRISPR are being used to develop crops with enhanced resistance to pests and diseases. It has also spread its wings into the field of entomology where editing of *sxl* gene in *Spodoptera frugiperda* impacted the overall fecundity and hatching rate (Chikmagalur *et al.*, 2023).
- **Genetic Surveillance:** Genetic tools help track the evolution of pest resistance and monitor the spread of pests, allowing for timely adjustments in management strategies.

Sustainable and Eco-Friendly Practices

- **Reduced Risk Pesticides:** IPM 2.0 emphasizes the use of reduced-risk pesticides, which are less harmful to non-target organisms and the environment. These include natural and organic options.
- **Cover Crops and Crop Rotation:** Utilizing cover crops and implementing crop rotation strategies help disrupt pest life cycles and enhance soil health, reducing the need for chemical interventions.

Data Integration and Cloud Computing

- **Centralized Databases:** Cloud-based platforms allow for the integration of various data sources, including weather forecasts, pest monitoring data, and historical records. This centralized approach facilitates more informed decision-making. Intelligent Insect Monitoring System (I^2 MS) aims to early detect pests of fields using a system to attract insects by creating several stimuli (chromatic, food, sexual, and UV light). This I^2 MS takes a picture of the insect and uses Cloud Based Machine Learning (ML) algorithms to classify the image, then checks if the insect is dangerous to the crops or not (Sobreiro *et al.*, 2019).
- **Farm Management Software:** Modern farm management software integrates IPM practices with other aspects of farm management, providing a holistic approach to pest control and crop management. An ontology-based Decision support systems (DSS) can mention the AgriEnt (Lagos-Ortiz *et al.*, 2020) web platform, which leverages expert knowledge of insect pests affecting Ecuadorian crops to provide decision support for crop pest management through a rule-based inference engine.

Public Awareness and Education

- **Farmer Training:** Ongoing education and training programs help farmers understand and adopt new IPM technologies and techniques. Workshops, online courses, and extension services play a crucial role in disseminating knowledge.
- **Consumer Education:** Educating consumers about the benefits of IPM and sustainable pest management practices can increase support for environmentally friendly agriculture.

Challenges and Considerations

- **Cost and Accessibility:** The adoption of advanced technologies can be costly, and accessibility may vary depending on the region and resources available to farmers.
- **Data Security and Privacy:** With the increased use of digital tools, ensuring data security and privacy is essential to protect sensitive information.

Conclusion

IPM 2.0 represents a major advancement in pest management, combining new technologies and techniques to enhance effectiveness, sustainability, and precision. By integrating smart monitoring systems, such as IoT sensors and automated traps, with advanced biological controls, AI-driven decision support, and genetic tools, IPM 2.0 offers innovative solutions for managing pests. These technologies provide real-time data and predictive insights, enabling proactive and targeted pest control. Advances in biological control and genetic tools promote sustainability by improving pest resistance and offering eco-friendly alternatives to chemical pesticides. Additionally, cloud computing and centralized databases improve data integration and decision-making, supporting a comprehensive approach to farm management.

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