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Artificial Intelligence in Insect-Pest Management

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The global population is rapidly increasing and is projected to reach 10 billion by 2050, creating immense pressure on agriculture to boost crop production and yield per hectare (FAO, 2017). Various challenges including small land holdings, labor shortages, climate change, extreme weather conditions, and declining soil fertility are adversely affecting agricultural profitability. To address food shortages, two primary solutions have emerged: expanding agricultural land and embracing advanced technologies (Bacco et al., 2019). In densely populated countries like India, where land expansion is impractical, a promising approach is harnessing digital technologies. Digitalization provides precise data for optimizing production systems and nurturing innovative production and consumption models (Lajoie-O'Malley et al., 2020).

Artificial intelligence (AI) is an emerging digital technology in agriculture, reflecting human cognitive abilities to address problems (Liu, 2020). Recent decades have witnessed climate-related challenges like global warming, droughts, and extreme weather events (Piao et al., 2010) that have posed threats to traditional agricultural practices and introduce new uncertainties. Climate change also elevates pest issues, triggering international exchanges of infested materials (Dent et al., 1995). Pest-related complications, including resistance and secondary outbreaks, compound agricultural challenges (Weller et al., 2014). Effectively addressing these challenges mandates sustainable productivity increases while efficiently managing resources such as water, energy, pesticides, and fertilizers. AI has emerged as an important solution to optimize agricultural inputs while increasing agricultural output (Azfar et al., 2015). This article delves into AI's influence on insect pest management and explores the future of digital innovation in agriculture.

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Need for AI in Agriculture:

Agriculture, being labour-intensive, demands automation due to the growing global population and increasing demand for agricultural production. AI plays a pivotal role in assisting farmers across various aspects of agriculture by introducing innovative technologies like predictive analytics and enhanced farm and crop management systems, ensuring both crop quality and supply. Tools like satellite imagery facilitates precise land area determination and real-time crop health monitoring, offering valuable insights to farmers regarding demand levels, optimal crop varieties, pest monitoring, pesticide utilization, and predictive patterns (Subeesh and Mehta, 2021). Food producers grapple with challenges and threats posed by pests and diseases to their crops. Climate change, monoculture practices, and extensive pesticide use exacerbate these issues, making agricultural expansion crucial in the coming years. AI solutions, including agricultural automation and predictive analytics, offer viable strategic solutions (Beloev et al., 2021).

AI in Insect Pest Management:

The effectiveness of AI in addressing agricultural challenges relies on data quality, but accessing necessary information at the farmer level presents challenges. Combining image classification techniques with data from remote and local sensors can revolutionize agriculture, especially in early pest detection (Perea et al., 2019). Monitoring agricultural activities throughout the plant growth cycle is of paramount importance. AI systems, leveraging data from precision agricultural software, soil sensors, drones, computer vision, mechatronics, machine learning, remote sensing technologies, and even smartphone photos, can continuously track pest levels in crops and compare them to historical patterns (Mkrttchian, 2021). This enables timely pest management interventions. The increasing pollution and weather unpredictability further complicate pest control timing due to climate change, where AI plays a critical role by providing insights into how weather conditions affect crop cycles, helping farmers in predicting pest infestations and planning crop management strategies accordingly.

AI in Pest Management:

1. **Forecasted Agricultural Data**: AI technology plays an important role in forecasting various agricultural conditions, including weather, soil quality, groundwater levels, crop cycles, and the detection of plant diseases. AI solutions manage this data effectively, often employing unsupervised machine learning algorithms, enhancing agricultural output and reducing crop losses(Rizvi et al., 2021).
2. **Efficient Results for Farmers**: AI enables farmers to achieve greater productivity with less effort by combining hardware solutions, data collection software, and robotics,

tailored to specific agricultural challenges. It can predict pests, identify wasteful resource consumption patterns, improve decision-making, increase farmer profitability, and deploy AI agri bots (Fadziso, 2019).

3. **Maximized Output**: AI helps reduce the risk of crop failure and minimize errors in agricultural operations through forecasting and predictive analytics. It enhances crop resilience to pests and environmental conditions by collecting data on plant growth (Sharma et al., 2021).

AI Bolstering ICT Tools in Pest Management:

1. **IoT (Internet of Things):** IoT-based sensors enables continuous monitoring of factors such as insect pest infestations, offering precise data to refine farming techniques. IoT introduces accuracy, real-time monitoring, and data sharing, streamlining agricultural logistics (Jain et al., 2012).
2. **Farming Automation:** Autonomous machines, including self-driving tractors and unmanned aerial and ground vehicles, address labour shortages and reduce errors. They enhance precision farming, maximize output, and minimize resource usage (Songol et al., 2021).
3. **Sensors Technology:** Sensors provide valuable information to farmers, enabling increased crop yields while efficiently using resources like water, pesticides, and fertilizers. This is a challenge (Kaur et al., 2018).
4. **UAVs (Drones):** Drones with sensors are used for tasks like crop assessment, monitoring, planting, spraying, and field analysis. They reduce environmental impact and groundwater contamination, aligning with sustainable agriculture goals (El Hoummaidi et al., 2021).
5. **Software Solutions:** Machine learning and deep learning enhances crop monitoring, pest detection, and disease identification (LeCun et al., 2015). They assist in early pest detection, forecasting, and efficient resource utilization.
6. **Remote Sensing:** Remote sensing coupled with GPS, GIS, and VRT allows precise crop management, helping farmers manage pest damage, optimize pest control, and reduce cultivation costs (Anonymous, 2011). It offers insights into crop health and pest infestations.
7. **Expert Systems and DSS:** Expert systems provide tailored recommendations for managing pests and diseases, optimizing resource allocation, and machinery utilization. Decision Support Systems aid decision-making by suggesting management options and simulating their consequences (Rafea, 2009).

8. **Computer Vision:** Computer vision technologies are used for monitoring pest populations and pest traps, reducing labor-intensive tasks and enabling early pest identification (Shimoda et al., 2006).

Bottlenecks and Future Prospects of AI adoption in Insect pest management

The adoption of AI in agriculture, especially in insect pest management, faces significant challenges. Farmers often lack the time and digital skills to seamlessly integrate AI into their existing practices. To effectively implement AI in agriculture, new solutions must harmonize with established farming systems. Many farmers, especially in rural areas, are unaware of technological advancements and lack the technical knowledge needed for AI adoption. As awareness measures and technology becomes more accessible, agriculture may shift toward a semi-autonomous model guided by AI.

AI heavily relies on data for training and accuracy, but obtaining temporal data, especially crop-specific data, can be challenging, as it is primarily collected once a year during the growing season. This limits the development of robust AI models, making AI more prevalent in agronomic products like seeds, fertilizers, and pesticides rather than on-field precision solutions.The high cost of cognitive farming solutions is another barrier to widespread adoption. Making AI solutions more economically viable, possibly through open-source platforms, can accelerate adoption and knowledge among farmers.

Looking ahead, AI promises innovative and precise solutions to agricultural challenges, from pest control to farm operations optimization. AI has potential to empower farmers to become skilled manpower, using data to optimize yields down to individual rows of plants. Future technological advancements will benefit AI-based products in agriculture, addressing food supply challenges for a growing global population. To ensure AI's inclusive future in agriculture, efforts must extend access to small farms in remote regions. AI holds great promise for the industry, optimizing resource utilization, mitigating shortages, and advancing research in pest management and beyond.

In conclusion, AI is transforming agriculture by addressing challenges in insect pest management through various technologies like IoT, farming automation, sensors, UAVs, and software solutions. These innovations enable precise monitoring, early pest detection, efficient resource utilization, and increased farmer profitability. AI is poised to play a pivotal role in ensuring food security for the growing global population while promoting sustainable agricultural practices.

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