

AGRISAARTHI- Pesticide Use and Safe Exports

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Abstract—Agriculture continues to face persistent challenges related to pest management and pesticide misuse, which directly affect crop quality, food safety, and regulatory compliance. In recent years, machine learning has emerged as a promising tool to support intelligent decision-making in agricultural advisory systems, particularly for pest identification and pesticide recommendation. However, a critical limitation of many existing approaches is the absence of regulatory awareness, especially with respect to Maximum Residue Limits (MRLs) enforced by national and international food safety authorities.

This paper presents a structured review of machine learning-based pesticide recommendation systems reported in recent literature, examining commonly used models, data sources, and system architectures. The review highlights the growing reliance on supervised learning and deep learning techniques while identifying gaps in compliance-oriented decision support. To contextualize the reviewed methods, a prototype decision-support framework, referred to as AgriSaarthi, is discussed as an illustrative example of integrating machine learning-driven recommendations with MRL reference information.

The analysis emphasizes the need for compliance-aware agricultural advisory platforms that move beyond prediction accuracy and incorporate food safety considerations. The study concludes that aligning machine learning techniques with regulatory constraints can contribute to safer pesticide practices and support the long-term sustainability of modern agriculture.

Index Terms— -Machine Learning; Pesticide Recommendation; Maximum Residue Limits; Agricultural Advisory Systems; Decision-Support Framework; Sustainable Agriculture

I. INTRODUCTION

Agriculture remains a vital sector for economic stability, food security, and rural livelihood, particularly in developing countries such as India. However, crop productivity and quality continue to be

significantly affected by pest infestations and plant diseases. To mitigate these challenges, pesticides are widely used as a primary control mechanism. While pesticides play an essential role in safeguarding crops, their excessive or improper application has led to serious concerns related to food safety, environmental degradation, and human health risks. One of the most critical consequences of pesticide misuse are the presence of chemical residues in agricultural produce beyond permissible safety thresholds.

To address these risks, regulatory authorities such as the Food Safety and Standards Authority of India (FSSAI), Codex Alimentarius Commission, and the European Union have established Maximum Residue Limits (MRLs), which define the legally acceptable concentration of pesticide residues in food commodities. Compliance with these limits is mandatory for both domestic consumption and international trade. Despite the availability of such regulations, farmers often lack accessible, decision-oriented tools that translate regulatory information into actionable guidance at the field level. As a result, pesticide application decisions are frequently based on generalized recommendations, vendor advice, or past experience rather than data-driven and compliance-aware insights.

Recent advances in machine learning and artificial intelligence have enabled the development of intelligent agricultural advisory systems aimed at pest identification, disease detection, and pesticide recommendation. Studies employing convolutional neural networks, DenseNet architectures, and ensemble learning models have demonstrated high accuracy in identifying crop diseases and pest categories from image and structured data. Survey-based research further indicates that supervised learning techniques such as Decision Trees and Random Forests are particularly effective for pesticide recommendation tasks due to their robustness,

interpretability, and suitability for structured agricultural datasets. While these approaches have improved prediction accuracy and automation, most existing systems prioritize pest or disease recognition and largely overlook regulatory constraints associated with pesticide residues.

Parallel research in pesticide toxicity prediction and environmental risk assessment highlights the growing importance of integrating safety considerations into intelligent agricultural systems. Review studies emphasize that machine learning models can play a crucial role not only in improving agricultural efficiency but also in reducing human exposure to hazardous chemicals by supporting informed pesticide selection. However, a clear gap persists between predictive modeling and regulatory compliance, as MRL standards are rarely embedded directly into recommendation frameworks.

In this context, there is a growing need for compliance-aware decision-support systems that combine machine learning-based pesticide recommendation with regulatory reference information. Addressing this gap, the present work reviews existing machine learning approaches used in pesticide recommendation systems and discusses a prototype framework, referred to as AgriSaarathi, to illustrate how predictive models can be complemented with MRL awareness. By aligning machine learning outputs with food safety regulations, such systems have the potential to promote responsible pesticide usage, enhance agricultural sustainability, and support safer food production practices.

II. LITERATURE SURVEY

Paper 1: Intelligent Insecticide and Fertilizer Recommendation System Based on TPF-CNN for Smart Farming.

Authors: Tanmay Thorat, B. K. Patle, Sunil Kumar Kashyap

This study proposes an intelligent agricultural recommendation system that integrates pest identification and insecticide recommendation using a Transition Probability Function-based Convolutional Neural Network (TPF-CNN). The system combines image-based pest recognition with soil nutrient analysis using sensor data to recommend insecticides and fertilizers. Experimental results demonstrate high accuracy in identifying multiple pest classes and

timely recommendation delivery.

The core component of the proposed system is a Transition Probability Function-based Convolutional Neural Network (TPF-CNN). Unlike conventional CNN models that rely solely on spatial feature extraction, the TPF-CNN incorporates probabilistic transitions between feature states to enhance classification robustness. This approach enables the model to capture both discrete and continuous variations in pest appearance, which is particularly useful in real-world agricultural settings where lighting conditions, pest orientation, and background noise vary significantly.

Despite its technical sophistication, the system primarily focuses on treatment effectiveness and automation. It does not consider food safety regulations, such as Maximum Residue Limits (MRLs), during the recommendation process. The insecticide suggestions are based on pest identification accuracy rather than regulatory compliance or residue safety constraints. Additionally, the reliance on image capture hardware and sensor infrastructure increases system complexity and deployment cost, potentially limiting adoption among small-scale farmers.

These limitations highlight a critical research gap: while advanced deep learning models can accurately identify pests and recommend treatments, regulatory awareness and residue compliance are not integrated into the decision-making process. This gap directly motivates the need for compliance-aware systems, such as the approach discussed in the present work, which complements machine learning-based recommendations with MRL reference information.

Paper 2: A Survey on a Model for Pesticide Recommendation Using Machine Learning.

Authors: Vijaya Lakshmi S. Abbigeri, Geetha D. Devanagari

This survey paper provides a comprehensive overview of machine learning techniques applied to pesticide recommendation systems. It categorizes approaches into supervised, unsupervised, and regression-based models, highlighting algorithms such as Decision Trees, Random Forests, Support Vector Machines, and Neural Networks. The study emphasizes the role of data-driven decision-making in optimizing pesticide selection and dosage.

Among these, Random Forest is identified as

particularly effective due to its robustness, resistance to overfitting, and suitability for structured agricultural datasets. The paper also discusses regression models, including linear regression and artificial neural networks, which are commonly used for estimating pesticide dosage levels. In addition, unsupervised learning techniques such as clustering, dimensionality reduction, and association rule mining are explored for identifying hidden patterns in pest behavior and treatment effectiveness. The authors conclude that although machine learning shows strong potential in optimizing pesticide usage, most existing systems primarily focus on recommendation accuracy and operational efficiency while neglecting critical regulatory and food safety considerations. Specifically, the absence of mechanisms to incorporate Maximum Residue Limit (MRL) compliance is identified as a significant research gap, indicating the need for future systems that combine intelligent pesticide recommendation with regulatory awareness to ensure both agricultural productivity and consumer safety.

Paper 3: Systematic Approaches to Machine Learning Models for Predicting Pesticide Toxicity

Authors: Ganesan Anandhi and M. Iyapparaja Anandhi and Iyapparaja, in their review present a detailed and structured analysis of how machine learning techniques have been employed to assess the toxic effects of pesticides on human health and the environment. The authors highlight that while pesticides play a vital role in improving agricultural productivity, their widespread and prolonged use has resulted in serious concerns related to environmental contamination, bioaccumulation, and adverse health outcomes such as respiratory disorders, reproductive issues, and increased cancer risk.

The paper systematically examines recent research published between 2014 and 2023, focusing on machine learning models used to predict pesticide toxicity based on chemical properties, molecular descriptors, and exposure patterns. Various algorithms, including Decision Trees, Random Forests, Support Vector Machines, Artificial Neural Networks, and ensemble learning methods, are analyzed with respect to their predictive performance, interpretability, and data requirements. The authors emphasize that machine learning models are capable

of identifying complex, non-linear relationships between pesticide composition and toxicological impact, which are difficult to capture using traditional statistical approaches.

Additionally, the review discusses the availability and limitations of toxicity-related datasets, noting challenges such as data imbalance, limited real-world exposure data, and difficulties in model generalization. A key contribution of the paper is its emphasis on the role of machine learning in supporting regulatory decision-making by enabling early identification of high-risk pesticides and promoting safer chemical alternatives. However, the authors also acknowledge that most existing toxicity prediction studies operate independently of practical agricultural recommendation systems and lack integration with field-level decision support tools. The review concludes that although machine learning offers strong potential for predicting pesticide toxicity and reducing health and environmental risks, future research must focus on bridging the gap between toxicity prediction, regulatory compliance, and practical pesticide advisory systems to ensure safer and more sustainable agricultural practices.

Paper 4: Pesticide Recommendation for Different Leaf Diseases and Related Pests Using Multi-Dimensional Feature Learning Deep Classifier.

Author: Jaithoon Bibi Mohammed Saleem and Karpagavalli Shanmugam

The study presents an advanced decision-support framework that integrates deep learning with rule-based reasoning to improve pesticide recommendation for crop leaf diseases and associated pests. The approach is based on the understanding that accurate disease identification alone is insufficient for effective crop protection, as inappropriate pesticide selection can lead to environmental damage, increased pest resistance, and reduced agricultural productivity. To address this issue, the proposed system combines a multi-dimensional deep convolutional neural network (DCNN) for classifying leaf diseases and pests with a Rough Set–based fuzzy decision model for recommending suitable pesticides. The framework incorporates multiple heterogeneous features, including leaf image data, pest information, soil properties, climatic conditions, and pesticide characteristics, enabling the model to capture complex

interdependencies influencing disease occurrence and treatment outcomes.

Feature learning techniques are employed to enhance classification accuracy, while fuzzy rule-based reasoning improves interpretability and decision consistency. Experimental results demonstrate that the hybrid deep learning and decision-rule approach outperforms conventional machine learning models in terms of recommendation accuracy and adaptability

across different crops and regions. However, the system primarily emphasizes predictive performance and operational efficiency, without incorporating regulatory constraints related to pesticide residue safety or Maximum Residue Limit (MRL) compliance. Consequently, while the model contributes significantly to intelligent disease and pest management, it does not address food safety regulations or export-related requirements.

III. COMPARISON

Paper	Advantages	Limitations	Proposed Solution
1	Provides a clear overview of ML techniques for pesticide recommendation and highlights suitable models like RandomForest.	No practical implementation or regulatory compliance discussion.	Establishes a theoretical foundation for ML-based pesticide advisory systems.
2	Uses deep learning with multi-dimensional agricultural features for accurate recommendations.	High computational cost and no consideration of MRL or safety regulations.	A hybrid deep learning-based pesticide recommendation framework.
3	Analyzes ML models for predicting pesticide toxicity and health risks.	Focuses on toxicity prediction, not farmer-level recommendations.	Uses ML to identify harmful pesticides and support safety assessment.
4	High disease detection accuracy using deep learning.	Resource-intensive and lacks Regulatory compliance integration.	Automated disease detection with pesticide recommendation.

IV. CONCLUSION

The reviewed literature demonstrates that machine learning and deep learning techniques have significantly advanced the development of intelligent agricultural advisory systems, particularly in the areas of pest identification, disease classification, pesticide recommendation, and toxicity assessment. Prior studies highlight the effectiveness of supervised learning models such as Random Forest and ensemble methods for structured agricultural data, as well as deep learning architectures like CNN and DenseNet for image-based disease detection. Review-focused studies further emphasize the growing role of machine learning in assessing pesticide toxicity and associated health and environmental risks. However, despite these advancements, a common limitation across most existing works is the lack of integration between predictive intelligence and regulatory compliance mechanisms.

The majority of systems prioritize recommendation accuracy, computational performance, or classification efficiency, while overlooking food safety regulations such as Maximum Residue Limits (MRLs), which are critical for consumer health and

agricultural export acceptance. As highlighted in the project report, pesticide misuse and MRL violations remain major contributors to crop rejection and economic loss for farmers. This gap indicates the need for compliance-aware decision-support systems that combine machine learning-based recommendations with regulatory knowledge. Overall, the literature establishes a strong technical foundation for intelligent pesticide advisory systems but underscores the necessity of extending these models toward safer, regulation-aligned, and practically deployable solutions to support sustainable agriculture and informed pesticide usage.

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