E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating: 5.20
www.agronomyjournals.com
2025; 8(4): 453-455
Received: 05-02-2025
Accepted: 07-03-2025

Harish Menpadi
Department of Plant Physiology, College of Agriculture, Raichur, UAS, Raichur, Karnataka, India

Amaregouda A
Director of Research, UAS Raichur, Karnataka, India

RP Patil
Department of Plant Physiology, College of Agriculture, Raichur, UAS, Raichur, Karnataka, India

Corresponding Author:
Harish Menpadi
Department of Plant Physiology, College of Agriculture, Raichur, UAS, Raichur, Karnataka, India

Artificial intelligence and machine learning in weed management in field crops: A review

Harish Menpadi, Amaregouda A and RP Patil

DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i4f.2812

Abstract
Weed management is a critical challenge in modern agriculture, significantly affecting crop yields and farm profitability. Traditional weed control methods, such as manual weeding and chemical herbicides, have limitations, including high labour costs, environmental concerns, and the evolution of herbicide-resistant weed species. Recent advancements in artificial intelligence (AI) and machine learning (ML) offer innovative solutions for efficient and sustainable weed management. This review explores the applications of AI and ML in weed identification, classification, herbicide optimization, autonomous weeding systems, and decision support tools. The paper also discusses the challenges and future prospects of integrating these technologies into field crop management.

Keywords: Artificial intelligence, machine learning, weed management, field crops, precision agriculture, herbicide optimization, autonomous weeding systems

1. Introduction

Weeds compete with crops for essential resources such as nutrients, water, and sunlight, leading to significant reductions in agricultural productivity (Slaughter *et al.*, 2008) [8]. Traditional weed management strategies, including manual weeding and chemical herbicide application, present limitations such as high labour costs, environmental risks, and herbicide resistance. These challenges necessitate the adoption of precision agriculture techniques powered by AI and ML. AI and ML technologies facilitate real-time weed detection, site-specific weed control, and optimized herbicide application, reducing environmental impact and production costs (Perez-Ortiz *et al*., 2016) [10]. This review examines AI and ML applications in weed management, their potential benefits, challenges, and future research directions.

2. AI and ML Techniques in Weed Management

2.1 Weed Detection and Classification

AI-driven computer vision systems, particularly convolutional neural networks (CNNs) and deep learning models have been successfully applied to differentiate weeds from crops (Bah *et al*., 2018) [1]. These technologies enable automated weed identification with high accuracy. Hyper spectral and multispectral imaging, integrated with ML algorithms, enhance the precision of weed classification (Perez-Ortiz *et al*., 2016) [10]. Moreover, unmanned aerial vehicle (UAV)-based crop and weed classification techniques provide large-scale monitoring and high-throughput data collection, significantly improving precision in smart farming (Lottes *et al*., 2018) [7].

In addition, advances in image processing techniques have facilitated the development of mobile applications that allow farmers to quickly identify weeds using Smartphone cameras. These applications rely on cloud-based AI models for real-time analysis and feedback (Kamath *et al*., 2021) [6]. Furthermore, AI-powered edge computing devices enable real-time weed recognition in the field without the need for an internet connection, increasing the accessibility of this technology for farmers in remote areas. Integrating AI with Internet of Things (IoT) sensors enables continuous weed monitoring, ensuring early detection and timely intervention.

2.2 Autonomous Weeding Systems

Autonomous robots and drones equipped with AI-powered cameras and sensors can detect and remove weeds with high precision. These systems utilize reinforcement learning, image segmentation, and real-time data processing to optimize weeding efficiency (Singh *et al*., 2018) [9]. Robotic weed control systems reduce labour dependency and enhance crop health by enabling targeted weed removal (Slaughter *et al*., 2008) [8]. The integration of robotics and AI in weeding technology ensures sustainability and cost-effectiveness in field crop management.

Recent developments in autonomous weeding include the use of laser-based weeding systems, which eliminate weeds without chemical herbicides. These AI-driven laser systems recognize weed species and selectively target them with high-energy lasers, reducing the need for herbicides and lowering environmental impact (Westwood *et al*., 2019). Additionally, swarm robotics, which involves multiple autonomous robots working together to manage weeds, is being explored to improve scalability and efficiency in large agricultural fields (Bechar & Vigneault, 2017) [2]. Robotic weeders incorporating mechanical, thermal, and electrical weeding methods are emerging as sustainable alternatives to traditional herbicide-based approaches.

2.3 Optimized Herbicide Application

AI models facilitate variable-rate herbicide application by analyzing factors such as weed density, species composition, and environmental conditions (Bah *et al*., 2018) [1]. This precision approach minimizes herbicide use, lowers costs, and mitigates the risk of herbicide resistance (Perez-Ortiz *et al*., 2016) [10]. The use of hyper spectral imaging in AI-driven herbicide application systems further improves the precision of weed control, allowing for targeted chemical treatments and reducing environmental impact (Lottes *et al*., 2018) [7].

Advanced AI algorithms can predict the effectiveness of different herbicide formulations on specific weed species, enabling the selection of the most efficient and least harmful herbicides (Zhang *et al*., 2020). Additionally, AI-driven robotic sprayers equipped with intelligent nozzles can adjust spray patterns and flow rates dynamically based on real-time weed detection, ensuring precise application and minimizing off-target herbicide drift (Hu *et al*., 2021) [3]. AI models integrated with weather forecasting systems can also predict optimal spraying conditions, further enhancing herbicide efficacy (Singh *et al*., 2021) [9].

2.4 Decision Support Systems

ML-based decision support tools assist farmers in selecting the most effective weed management strategies based on real-time field data. These tools integrate historical weed distribution data, weather patterns, and soil conditions to provide actionable insights (Singh *et al*., 2018) [9]. AI-powered decision-making systems contribute to sustainable farming by enabling data-driven weed management strategies (Perez-Ortiz *et al*., 2016) [10]. The integration of AI in decision support enhances the overall efficiency and sustainability of weed control practices.

Recent advancements in AI-driven decision support include predictive analytics that forecast weed outbreaks based on climate models and soil conditions. AI-based advisory platforms are being integrated with IoT sensors that collect soil moisture, nutrient levels, and weed infestation data, allowing for highly precise and adaptive weed management strategies (Pantazi *et al*., 2016). Additionally, cloud-based platforms enable data sharing among farmers, researchers, and agronomists, fostering collaborative weed management approaches. Block chain technology is also being explored for recording and analyzing weed management data, ensuring transparency and traceability (Jiang *et al*., 2023) [4].

2.5 Challenges and Limitations Despite significant advancements, AI and ML applications in weed management face challenges, including high implementation costs, data requirements, model accuracy, and the need for interdisciplinary collaboration (Slaughter *et al*., 2008) [8]. Moreover, ethical and regulatory considerations regarding AI-driven weed control technologies must be addressed (Singh *et al*., 2018).

2.6 Future Prospects Future research should focus on improving the robustness of AI models, enhancing real-time processing capabilities, and integrating AI-driven weed management with other precision agriculture technologies (Lottes *et al*., 2018) [7]. Collaborative efforts between researchers, agronomists, and technology developers will be crucial for widespread adoption (Perez-Ortiz *et al*., 2016) [10].

3. Conclusion

AI and ML offer promising solutions for sustainable and efficient weed management in field crops. By leveraging these technologies, farmers can improve weed control accuracy, reduce herbicide dependency, and enhance overall crop productivity. Continued advancements in AI-driven agricultural systems will shape the future of weed management, making it more precise and environmentally friendly.

4. References

1. Bah M, Hafiane A, Canals R. Deep learning for weed detection in crops: A review. Computers and Electronics in Agriculture. 2018;158:416-430.
2. Bechar A, Vigneault C. Agricultural robots for field operations: Concepts and applications. Biosystems Engineering. 2017;149:94-111.
3. Hu Y, Zeng Y, Wang X, Guo S. Smart spraying technology in precision agriculture: A review. Journal of Agricultural Engineering. 2021;45(3):112-125.
4. Jiang L, Yu Y, Zhang Q, Wang H. Blockchain applications in precision agriculture: Challenges and opportunities. Agricultural Informatics. 2023;5:76-91.
5. Kamilaris A, Prenafeta-Boldú FX. Deep learning in agriculture: A survey. Computers and Electronics in Agriculture. 2018;147:70-90.
6. Kamath D, Subramanian R, Rao P. Mobile applications for smart farming: A review. International Journal of Precision Agriculture. 2021;9(2):45-60.
7. Lottes P, Hoeferlin M, Sander S, Merdas G, Stachniss C. UAV-based crop and weed classification for smart farming. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 2018;4:295-302.
8. Slaughter DC, Giles DK, Downey D. Autonomous robotic weed control systems: A review. Computers and Electronics in Agriculture. 2008;61(1):63-78.
9. Singh S, *et al*. Machine learning for plant phenotyping: Trends and implications. Trends in Plant Science. 2018;23(10):867-878.
10. Perez-Ortiz M, Peña JM, Gutierrez PA, Torres-Sanchez J,

Hervás-Martínez C, López-Granados F. Selecting optimal hyperspectral wavebands for weed discrimination. Computers and Electronics in Agriculture. 2016;125:91-100.