

# Utilizing Precision Technologies for Weed Control in Rainfed Agriculture

**Shabir Ahmad Bhat<sup>1\*</sup>, Fayaz Ahmed Bahar<sup>2</sup>, Bilal Ahmad Lone<sup>2</sup>,  
Waseem Raja<sup>2</sup>, Tauseef Bhat<sup>3</sup>, Bisma Jan<sup>1</sup>, Insha Ali<sup>1</sup>, Bisma Nazir<sup>1</sup>,  
Mehraj Ud Din Sofi<sup>1</sup>, Faseeha Khan<sup>1</sup> and Nadeem Khwaja<sup>4</sup>**

<sup>1</sup>Ph.D. Agronomy, <sup>2</sup>Professor cum Chief Scientist, <sup>3</sup>Assistant Professor, <sup>4</sup>Ph.D. Entomology,  
Division of Entomology, SKUAST-K

## Corresponding Author

Shabir Ahmad Bhat

Email: bhatshabir281@gmail.com



## OPEN ACCESS

### Keywords

Weed control, Precision agriculture, Weed management, Rainfed agriculture, Remote sensing, Variable rate technology (VRT), Artificial intelligence (AI).

### How to cite this article:

Bhat, S. A., Bahar, F. A., Lone, B. A., Raja, W., Bhat, T., Jan, B., Ali, I., Nazir, B., Sofi, M. U. D., Khan, F. and Khwaja, N. 2024. Utilizing Precision Technologies for Weed Control in Rainfed Agriculture. *Vigyan Varta* 5(12): 17-25.

## ABSTRACT

Weed management is a critical challenge in rainfed agriculture, where limited water availability amplifies competition between crops and weeds for essential resources. Traditional weed control methods, such as manual weeding or blanket herbicide application, are labour-intensive, environmentally harmful, and often ineffective in preventing herbicide resistance. Precision agriculture offers innovative solutions by integrating advanced technologies for efficient, targeted weed management. Key tools include remote sensing via satellites and drones, variable rate technology (VRT) for site-specific herbicide application, artificial intelligence (AI)-based weed identification, and autonomous weeding robots. These technologies enable timely weed detection, conserve water, reduce chemical use, and enhance crop yields. Despite challenges such as high initial costs, technical training requirements, and limited infrastructure in rainfed regions, the adoption of precision technologies has the potential to transform weed control practices. By minimizing resource wastage and mitigating environmental impacts, precision weed management offers a sustainable pathway for improving agricultural productivity and resilience in rainfed systems,

ensuring long-term food security under changing climatic conditions. Weeds pose a significant challenge to agricultural productivity, particularly in rainfed farming systems where water availability is naturally limited. These non-crop plants compete with cultivated crops for essential resources such as water, light, nutrients, and space, ultimately reducing crop yield and quality. Conventional weed management strategies rely heavily on chemical herbicides and labour-intensive practices, both of which can harm the environment and lead to herbicide resistance. In response, precision agriculture technologies are emerging as innovative solutions to address weed control efficiently, sustainably, and economically.

## INTRODUCTION

**W**eeds pose a persistent threat to agricultural productivity, especially in rainfed systems where water resources are limited. Competition from weeds significantly reduces crop yields by draining essential resources like water, sunlight, and nutrients. Traditional weed management practices—such as manual weeding, tillage, and herbicide application—are increasingly becoming unsustainable due to labour shortages, herbicide resistance, and environmental concerns (Dong *et al.*, 2017). Precision agriculture, using advanced technologies, offers promising solutions by enabling more targeted and sustainable weed control. In recent years, the integration of artificial intelligence (AI) in precision agriculture has become a transformative tool, offering innovative solutions to longstanding challenges. AI involves the capacity of machines to perform functions traditionally requiring human intelligence, such as problem-solving and decision-making. Weed management is one area where AI shows immense promise, as weeds compete with crops for critical resources like water, nutrients, and sunlight. Some weeds are also toxic, posing risks to human health, livestock, and public safety. While herbicides remain a common tool for controlling weeds, their widespread and often indiscriminate use poses significant environmental and health hazards. Excessive herbicide application contributes to groundwater contamination, affects soil

fertility, and creates health risks through exposure to toxic chemicals. In addition, herbicide-resistant weed populations have emerged as a consequence of overuse, reducing the effectiveness of conventional chemical control methods (Muchhadiya *et al.*, 2022).

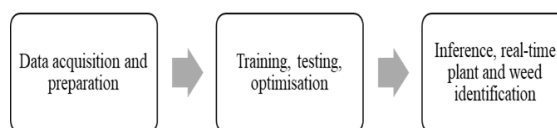
With herbicide prices rising and their availability becoming limited, farmers are increasingly searching for more sustainable and cost-effective alternatives. The current reliance on manual weeding is also problematic. Hand weeding, though effective, is highly labor-intensive and costly, especially as agricultural labor becomes scarce. Similarly, mechanical tillage can damage soil health by disrupting microbial communities, increasing soil erosion, and causing nutrient runoff, which further threatens agricultural sustainability. AI-based weed management offers a viable solution to these issues by enabling precise and efficient control strategies. With advanced technologies like machine vision and deep learning, AI systems can accurately identify and target specific weed species, minimizing herbicide usage. This reduces environmental contamination and lowers risks to human health. Additionally, AI tools can optimize herbicide application rates by using variable-rate technology, ensuring only the required amount is applied to specific areas. This reduces the accumulation of herbicides in the soil, which could otherwise

inhibit the germination of sensitive subsequent crops. Moreover, AI-driven weed control systems, such as autonomous robots equipped with sensors and cameras, can perform non-chemical weeding methods like mechanical extraction or thermal control. These innovations eliminate the need for manual intervention while maintaining soil health. In sum, AI technologies offer a sustainable approach to weed management, addressing key challenges such as herbicide resistance, soil degradation, and labour shortages, paving the way for more resilient and environmentally friendly agricultural practices.

### Machine Learning Techniques for Weed Identification

- ❖ **Convolutional neural networks (CNN):** CNN is used to classify weeds and crops, whereas the shallow network is used to detect weeds.
- ❖ **Deep convolutional neural network (DCNN):** High-throughput phenotyping and accurate field management of resistant weeds.
- ❖ **Support vector machine (SVM):** Identification of weeds, predict herbicide resistance in weeds, determine the appropriate herbicide.
- ❖ **Artificial neural networks (ANNs):** Classify the weed species based on the color, texture, and leaf of weeds.
- ❖ **Random Forest (RF) classifier:** Real-time detection of the weed and crop for precision UAV spraying.
- ❖ **k-nearest neighbours (KNN):** Evaluating crop damage from herbicides, Weed classification for Realtime automatic sprayer.

- ❖ **ShuffleNet-v2 and VGGNet:** Detecting and discriminating weeds susceptible to herbicide (Ghatrehsamani *et al.*, 2023).



**Fig. 1: Plant and weed identification pipeline using AI**

### Applications of AI in Weed Management

1. **Automated Weed Identification**  
 Machine vision systems, combined with AI algorithms, enable real-time identification of weed species within crop fields. By analysing images from drones or ground-based sensors, these systems distinguish between crops and weeds, ensuring targeted interventions without harming beneficial plants.
2. **Precision Herbicide Application**  
 AI-powered sprayers equipped with computer vision and GPS can selectively spray herbicides only where weeds are detected. This reduces herbicide usage, lowering environmental contamination and costs while preventing damage to crops.
3. **Weeding Robots**  
 Autonomous robots use AI algorithms to navigate fields and mechanically remove weeds without chemicals. Some robots employ machine learning to adapt to changing field conditions and improve their weed-detection accuracy over time. Examples include EcoRobotix and Nano Technologies' robots, which are equipped with solar-powered systems for energy efficiency.
4. **Weed Mapping and Monitoring**  
 AI-driven drones and satellites capture high-resolution images of fields, helping create detailed weed maps. These maps guide farmers in understanding weed

density, location, and spread, enabling site-specific weed management that saves resources and improves efficiency

#### 5. Predictive Weed Management

AI systems analyse environmental and historical data to forecast weed outbreaks based on factors like weather patterns, soil conditions, and crop cycles. This predictive capability helps farmers prepare timely weed control strategies to prevent infestations before they occur.

#### 6. Herbicide Resistance Management

AI-based tools analyse weed populations to detect herbicide-resistant strains and suggest alternative control measures. This proactive approach minimizes resistance buildup and promotes sustainable weed management practices by rotating herbicides and integrating non-chemical methods.



MAJOR TOOLS USED FOR WEED MANAGEMENT UTILIZING PRECISION TECHNOLOGIES

#### SEE and SPRAY Technique

Innovative technologies such as “See & Spray” are transforming weed management through advanced artificial intelligence (AI), machine learning, and big data analytics. This automated system integrates sensors and cameras to distinguish between crops and weeds, achieving herbicide savings of up to 90%. Unlike traditional methods that rely on plant spacing or color differences, “See & Spray” can recognize subtle distinctions between plant species under complex

conditions, even those that may challenge human perception.

#### Unmanned Aerial Vehicles (Drones) for Weed Detection

Drones, also known as **Unmanned Aerial Vehicles (UAVs)**, are now essential tools for precision agriculture (Daponte *et al.*, 2022). They play a critical role in early weed detection by capturing high-resolution aerial images of crop fields. Using **Normalized Difference Vegetation Index (NDVI)** data and post-flight image analysis, drones generate weed maps that highlight areas of intense weed growth, distinguishing them from healthy crops. This timely identification allows farmers to implement targeted control strategies, reducing resource waste and improving crop performance (Raj *et al.*, 2020).



Weed monitoring drones

#### Weed Detection Robots for Automated Control

In the realm of precision agriculture, **robotic weeders** represent a major breakthrough. These systems use sophisticated sensors, cameras, GPS technology, and AI-based algorithms to navigate fields and precisely locate weed infestations. Unlike chemical control methods, most robotic systems (around 75%) employ **mechanical weeding techniques**, eliminating weeds without harming the soil ecosystem. Companies like **Blue River Technology, Carbon Robotics, Ecorobotix, and Zasso** are at the forefront of developing commercial robotic solutions for weed management (Rai *et al.*, 2023). These

robotic weeders not only reduce dependency on herbicides but also enhance long-term environmental sustainability. By automating weed control, they alleviate labour challenges in agriculture and optimize productivity, enabling farmers to manage larger areas more efficiently. Such technologies demonstrate how agriculture is shifting from traditional manual practices toward **data-driven, AI-powered innovations** that ensure precise and sustainable farming

### Weed detection robots

AI-powered precision agriculture uses computer vision and machine learning algorithms to accurately identify weeds within crop fields. These advanced systems can detect weeds faster and with higher precision than humans, enabling more efficient management. Weed detection using drones is particularly effective when combined with Convolutional Neural Networks (CNNs), a deep learning method that enhances classification accuracy. Sandeep *et al.* (2018) demonstrated that a carefully designed CNN can outperform previous models by improving the precision of weed detection and reducing false positives. In such systems, machine learning models are trained using large datasets containing labeled images of various weed species. By tagging each image with its corresponding weed type, the system learns to differentiate weeds based on their unique visual features (Adeniji *et al.*, 2023). Python-based machine learning techniques were employed to develop robust training models capable of identifying and classifying multiple weed types with minimal error. Additionally, machine vision systems integrated with drones or automated sensors use image filtering techniques to further improve weed detection. These tools simplify the monitoring process by scanning entire fields, generating detailed data on weed density, and ensuring that farmers can act promptly. The adoption of AI in weed management not only saves time and labor but

also offers sustainable solutions by minimizing herbicide use.

### Laser Weeding: A Chemical-Free Precision Solution

Laser weeding technology harnesses AI, robotics, and high-powered lasers to provide non-chemical, no-till weed control for modern agriculture. The system uses computer vision and deep learning models to precisely detect and eliminate weeds by targeting the meristem—the plant's growth center—without affecting crops. A major benefit of laser weeding is its ability to operate day or night and in any weather conditions, making it a versatile and reliable option for farmers. With the capability to eliminate up to 5,000 weeds per minute, this advanced solution boosts crop yield while reducing overall farming costs (Carbon Robotics, 2023).

**How Laser Weeders Work:** Laser weeders are designed as robotic systems that can be attached to the back of tractors, seamlessly integrating with farming equipment. These machines continuously scan the field, identifying weeds in real-time using AI-powered computer vision. They can detect weeds earlier in their lifecycle—before they become visible to the human eye—and eradicate them before they can harm crops. This precise technology can target weeds with millimeter-level accuracy, even between densely planted crops, ensuring thorough weed removal without disturbing the soil or damaging the plants.

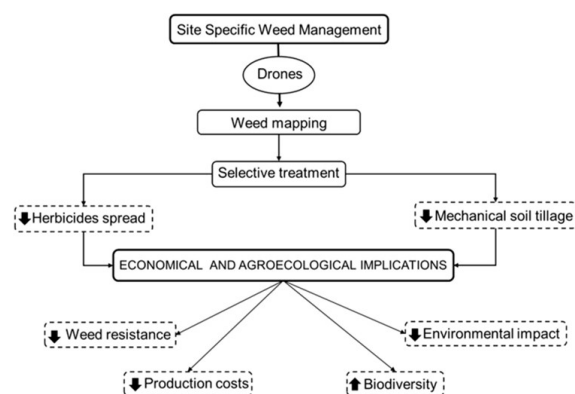
**Efficiency and Benefits:** With laser weeding technology, farmers can treat two acres of land per hour, significantly reducing labor and freeing time for other farm operations. The elimination of herbicides lowers environmental impact and mitigates the risk of herbicide-resistant weeds. Additionally, because this method avoids soil disturbance, it preserves soil health and reduces erosion—an

important aspect of sustainable farming. Laser weeding offers a cost-effective, environmentally friendly alternative to chemical weed control. The precision and automation that it provides, makes it an invaluable tool for modern agriculture, helping farmers reduce input costs and improve productivity without compromising sustainability.

### Site-specific weed management

SSWM offers a highly effective and environmentally responsible method for controlling weed populations through precise, data-driven strategies. This approach enables continuous monitoring, mapping, and targeted weed control that can be tailored to the specific conditions of each agricultural field. Advanced technologies such as Unmanned Aerial Vehicles (UAVs) equipped with high-resolution cameras and sensors help identify and classify different weed species (John et al., 2020). With the integration of GPS technologies, precise field mapping becomes possible, allowing large areas to be surveyed within minutes. The combination of UAVs, sensors, and GPS mapping makes it easier to optimize weed management by applying mechanical control methods or precisely targeting herbicide application only where needed. This targeted approach reduces chemical usage, slows the development of herbicide-resistant weeds, and enhances the effectiveness of non-chemical control methods. Additionally, SSWM improves biodiversity by minimizing the impact on non-target species and supports environmental sustainability through the reduced spread of agrochemicals. From an economic perspective, SSWM lowers production costs by improving resource efficiency and minimizing input waste. With more accurate planning and management, farmers can increase yields while reducing environmental harm. In the context of rising global food demands, SSWM offers a sustainable solution for future

agricultural systems by promoting ecological resilience and ensuring compliance with environmental regulations (López-Granados *et al.*, 2016). As agriculture moves toward sustainability, these technologies will play a critical role in balancing productivity with environmental stewardship (Lottes *et al.*, 2017).



### Site-specific weed management (SSWM) scheme realized by drones and its economical and agro-ecological implications

#### Benefits of AI-Based Weed Management

- ❖ Enhanced precision
- ❖ Autonomous spraying
- ❖ Solve the problem of herbicide resistance
- ❖ Reductions in herbicide use
- ❖ Solve the problem of herbicide residue
- ❖ Monitoring weed populations and tracking weed hot spots over time: By utilizing drone imagery and AI algorithms, identification of hot spots of weed infestation can be carried out.
- ❖ Improved crop productivity
- ❖ Clear path to organic farming
- ❖ Control of invasive weeds
- ❖ Integration with farming systems: Weed detection robots are designed to integrate

with existing farming systems seamlessly. They can communicate with other farm machinery and equipment, enabling coordinated weed management strategies. This integration optimizes the use of resources and ensures a holistic approach to weed control.

- ❖ **Accurate measurement of weed pressure:** Advanced AI technology provides accurate measurements of weed pressure in fields. By analyzing drone and satellite imagery, we are able to quantify weed density and assess the level of weed competition faced by crops. Gain valuable insights into weed growth patterns, adapt weed control strategies, and implement targeted interventions for maximum weed suppression is possible.
- ❖ **Reducing the need for manual labor:** By accurately assessing the weed density and coverage in fields, this technology helps to optimize resource allocation, streamline labor requirements, and improve the efficiency of weed control operations.
- ❖ **Estimation of man hours for weed control:** AI-driven system provides performance evaluation for hand labor involved in weed control. By analyzing drone imagery and other data sources, we help to assess the effectiveness and productivity of hand labor activities. Automate repetitive tasks, minimize reliance on manual labor, and achieve cost savings while maintaining effective weed control practices.

### Challenges of AI-Based Weed Management

While AI-powered weed management offers significant benefits, several challenges can hinder its widespread adoption. These challenges include technical, economic, and environmental constraints, as well as issues related to data handling and farmer acceptance.

1. **High Initial Costs and Infrastructure Requirements:** The development and deployment of AI-based weed management technologies, such as drones, robots, and precision sprayers, require significant investment. The cost of equipment, sensors, and software can be prohibitively high for small-scale farmers. Moreover, maintaining these systems, including repairs and software updates, demands additional resources and technical expertise.
2. **Complexity of Weed Identification:** AI systems rely on large datasets of weed images to train machine learning models for accurate detection. However, achieving high accuracy can be challenging due to variability in weed species, growth stages, and environmental conditions (Adeniji *et al.*, 2023). Inconsistent lighting, soil backgrounds, or crop residues can cause the system to misidentify weeds or miss them entirely.
3. **Data Management and Processing Limitations:** AI-based weed control systems generate massive amounts of data, especially when UAVs or cameras capture high-resolution images across large fields. Data storage, processing, and real-time decision-making can become bottlenecks, requiring sophisticated infrastructure and cloud-based solutions to handle the volume effectively.
4. **Limited Connectivity in Rural Areas:** Many agricultural regions suffer from poor internet connectivity, making it difficult to transmit data from UAVs or robots to cloud servers for analysis. This lack of infrastructure can delay decision-making and reduce the effectiveness of AI-based systems.
5. **Farmer Training and Adoption:** Many farmers may find AI technologies difficult to operate and manage, especially in regions where digital literacy is low.

Training farmers to use AI-based tools effectively and ensuring their acceptance of these innovations is a significant challenge. Resistance may also stem from skepticism about technology replacing traditional knowledge and concerns about job displacement.

#### 6. Environmental Constraints and Sustainability Issues:

Though AI-based systems are designed to be environmentally friendly, they are not entirely without challenges. Energy consumption from drones, robots, and computational operations can contribute to the carbon footprint of these technologies. Additionally, if not carefully managed, these systems may still leave some herbicide residues in the field or disturb non-target organisms, affecting biodiversity.

#### 7. Limited Adaptability to Diverse Cropping Systems:

AI tools often need to be customized for specific crops or farming conditions, which may limit their effectiveness in regions with diverse cropping patterns or small, fragmented farms. Additionally, weeds in mixed cropping systems or agroforestry setups can be harder to detect with current AI models.

### CONCLUSION

In conclusion, utilizing precision technologies for weed control in rainfed agriculture represents a promising advancement toward sustainable farming. By integrating site-specific management tools, such as remote sensing, GPS-guided herbicide application, and machine learning models, farmers can target weed infestations with high accuracy, reducing the need for widespread herbicide use and thus minimizing environmental impact. These technologies enable more efficient use of resources, which is particularly valuable in rainfed systems where water scarcity and fluctuating weather patterns add complexity to

weed management. Ultimately, precision weed control not only enhances crop productivity by reducing competition for essential resources but also contributes to soil health and biodiversity, aligning with the goals of resilient and eco-friendly agricultural practices. Embracing these technologies can help farmers overcome the challenges posed by climate change, supporting long-term agricultural sustainability and food security in rainfed regions.

### REFERENCES

- Adeniji AA, Jack KS, Idris MK, Oyewobi SS, Musa H, Oyelami AO. 2023. *AJERD*, 6(2): 28- 38.
- Carbon Robotics. 2023. <https://www.agritechtomorrow.com/article/2023/05/a-i-powered-laserweeding-a-new-tool-for-weedcontrol/14579>
- Ghatrehsamani S, Jha G, Dutta W, Molaei F, Nazrul F, Fortin M, Bansal S, Debangshi U, Neupane J. 2023. Artificial intelligence tools and techniques to combat herbicide resistant weeds-A review. *Sustainability*, 15, 1843.
- John KN, Valentin V, Abdullah B, Bayat M, Kargar MH, Zargar M. 2020. Weed mapping technologies in discerning and managing weed infestation levels of farming systems. *Res Crops*.
- Lottes P, Khanna R, Pfeifer J, Siegwart R, Stachniss C. 2017. UAV-based crop and weed classification for smart farming. *Proc IEEE Int Conf Robot Autom*.
- Muchhadiya RM, Kumawat PD, Sakarvadia HL, Muchhadiya PM. 2022. Weed management with the use of nano-encapsulated herbicide formulations: A review. *Pharma Innovation*, 11(12): 2068-2075.



- Rai N, Zhang Y, Rama BG, Schumacher L, Yellavajjala RK, Bajwa S, Sun X. 2023. Applications of deep learning in precision weed management: A review. *Computers and Electronics in Agriculture*, 206, 107698.
- Sandeep K, Rajeswari, Usha BN. 2018. *International Journal of Scientific Research and Review*, 7(6): 41-47
- López-Granados F, Torres-Sánchez J, Serrano-Pérez A, de Castro AI, Mesas-Carrascosa Fco-J, Peña J-M. 2016. Early season weed mapping in sunflower using UAV technology: variability of herbicide treatment maps against weed thresholds. *Precis Agric.*;17:183–99.
- Dong W, Liu E, Yan C, Tian J, Zhang H, Zhang Y. 2017. Impact of no tillage vs. conventional tillage on the soil bacterial community structure in a winter wheat cropping succession in northern China. *Eur J Soil Biol.*;80:35–42.
- Raj R, Kar S, Nandan R, Jagarlapudi A. 2020. precision agriculture and unmanned aerial vehicles (UAVs) BT unmanned aerial vehicle: applications in agriculture and environment. In: Avtar R, Watanabe T, editors. Cham: *Springer International Publishing*.
- Daponte P, Vito LD, Glielmo L, Iannelli L, Liuzza D, Picariello F, et al. 2019. A review on the use of drones for precision agriculture. *IOP Conf Ser Earth Environ Sci.*;275:012022.