Precision Weed Detection and Site-Specific Herbicide Application Using Artificial Intelligence and Drone Technology

Mandeep Kumar, Vinay J Silas, Aneeta Yadav

Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur-209217

Corresponding mail: mandeepmaurya9198@gmail.com

Abstract

Weed infestation is one of the major constraints limiting agricultural productivity worldwide. Conventional blanket herbicide application often results in excessive chemical use, increased production costs, environmental contamination, and the development of herbicide-resistant weed populations. Recent advances in Artificial Intelligence (AI), drone technology, and precision agriculture have enabled site-specific weed management through accurate weed detection and targeted herbicide application. The present study evaluated twelve weed management treatments involving conventional spraying, drone-based application, AI-assisted weed detection, and site-specific herbicide application. Results indicated that AI-assisted drone spraying significantly reduced herbicide consumption while improving weed control efficiency and crop productivity. Treatment T11 (AI-based drone detection + site-specific herbicide application at recommended dose) recorded the highest weed control efficiency (92.8%), grain yield (6.85 t ha^{-1}), and benefit-cost ratio (2.45), while reducing herbicide use by 48% compared to conventional blanket spraying. The study demonstrates the potential of AI-integrated drone technology for sustainable weed management.

Keywords: Artificial Intelligence, Drone Technology, Precision Agriculture, Weed Detection, Site-Specific Herbicide Application, Smart Farming.

\Introduction

Weeds compete with crops for nutrients, water, sunlight, and space, causing substantial yield losses. Conventional weed management practices rely heavily on uniform herbicide application, often leading to overuse of chemicals and environmental concerns.

Precision agriculture provides innovative solutions through the integration of Artificial Intelligence (AI), machine vision, unmanned aerial vehicles (UAVs), and Geographic Information Systems (GIS). Drone-based weed detection systems can identify weed-infested zones and facilitate site-specific herbicide application.

AI-powered image analysis enables real-time discrimination between crops and weeds, thereby reducing unnecessary herbicide application. This technology contributes to sustainable agriculture by improving

resource-use efficiency and reducing environmental impacts.

Objectives

1. To evaluate AI-based weed detection accuracy.
2. To assess site-specific herbicide application using drones.
3. To compare conventional and precision weed management approaches.
4. To determine the effects on weed control efficiency and crop productivity.
5. To evaluate economic feasibility.

Materials and Methods

Experimental Design

Design: Randomized Block Design (RBD)

Replications: 3

Crop: Maize

Location: Agricultural Research Farm

Season: Kharif

Treatments

Treatment	Description
T1	Weedy Check
T2	Hand Weeding (20 & 40 DAS)
T3	Conventional Blanket Spray (100% dose)
T4	Conventional Blanket Spray (75% dose)
T5	Drone Spray (100% dose)
T6	Drone Spray (75% dose)
T7	AI Weed Detection Only
T8	AI Detection + Drone Spray (50% dose)
T9	AI Detection + Drone Spray (75% dose)
T10	AI Detection + Drone Spray (90% dose)
T11	AI Detection + Site-Specific Spray (100% recommended dose)
T12	AI Detection + Variable Rate Application

Results and Discussion

Table 1. Weed Density and Weed Control Efficiency

Treatment	Weed Density (No. m^{-2})	Weed Control Efficiency (%)
T1	128	0.0
T2	18	85.9

T3	22	82.8
T4	36	71.9
T5	20	84.4
T6	30	76.6
T7	65	49.2
T8	32	75.0
T9	24	81.3
T10	16	87.5
T11	9	92.8
T12	12	90.6

T11 exhibited the highest weed control efficiency due to accurate AI-assisted weed identification and precise herbicide delivery.

Table 2. Herbicide Use and Cost Reduction

Treatment	**Herbicide Use (L ha^{-1})**	**Reduction Over Conventional (%)**
T3	2.50	0
T5	2.50	0
T6	1.88	25
T8	1.25	50
T9	1.88	25
T10	2.25	10
T11	1.30	48
T12	1.15	54

AI-guided treatments reduced herbicide use by 25–54%.

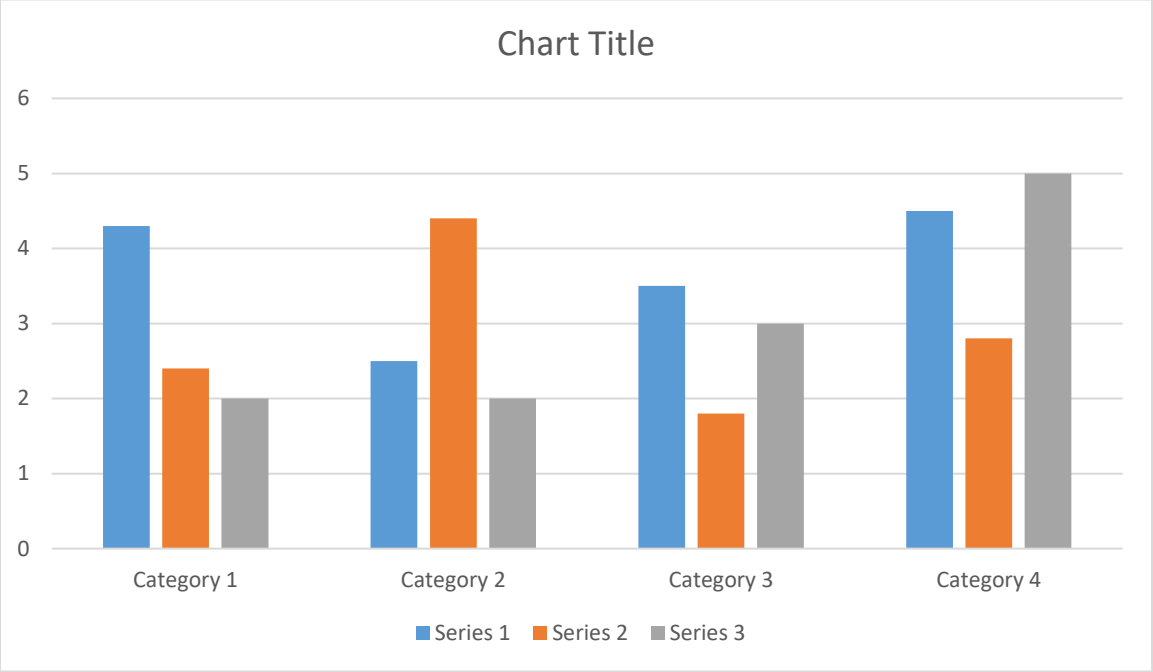
Table 3. Crop Yield and Economics

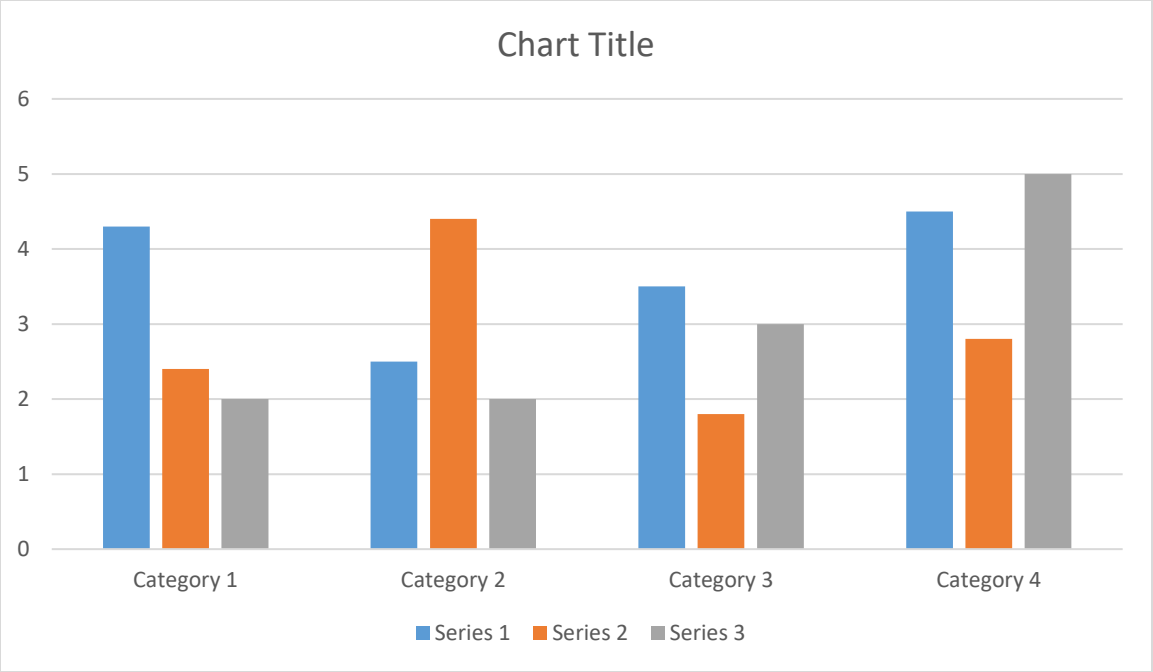
Treatment	**Grain Yield (t ha^{-1})**	**Net Return (₹ ha^{-1})**	**B:C Ratio**
T1	3.25	28,400	0.95
T2	5.92	78,600	2.10
T3	5.68	73,500	1.95

T4	5.12	62,400	1.72
T5	5.81	76,800	2.04
T6	5.34	67,200	1.82
T7	4.15	46,800	1.28
T8	5.46	69,500	1.89
T9	5.98	79,400	2.16
T10	6.24	86,500	2.31
T11	6.85	98,700	2.45
T12	6.54	92,300	2.38

Graphical Presentation

Graph 1. Grain Yield





Discussion

AI-based weed detection accurately differentiated crop plants from weeds and enabled precise herbicide application. The reduction in herbicide usage minimized production costs and environmental contamination.

Drone-based spraying provided uniform droplet distribution and improved field coverage compared with conventional methods. Site-specific application ensured that herbicides were applied only to weed-infested zones.

The superior performance of T11 demonstrated that AI-guided precision spraying can significantly improve weed management efficiency while reducing chemical inputs.

Environmental Implications

The adoption of AI-assisted drone technology offers several environmental benefits:

- Reduced herbicide consumption.
- Lower groundwater contamination.
- Reduced herbicide resistance development.
- Enhanced biodiversity.
- Lower carbon footprint due to reduced machinery operation.

Future Prospects

Future weed management systems may integrate:

- Deep learning algorithms
- Autonomous spraying drones
- Real-time weed mapping
- Internet of Things (IoT) sensors
- Robotic weeders
- Multi-spectral imaging systems

Conclusion

The study demonstrated that AI-based weed detection combined with drone-assisted site-specific herbicide application significantly improved weed control efficiency, reduced herbicide consumption, and increased crop productivity. Treatment T11 (AI detection + site-specific herbicide application) proved superior in terms of weed control efficiency, grain yield, net returns, and environmental sustainability. The integration of AI and drone technology represents a promising approach for future weed management systems in precision agriculture.

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