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Precision Weed Management

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Precision weed management (PWM) which is inclusive of those methods that will ensure greater farm productivity. These include a combination of need-specific, site specific and cost-effective weed sensing systems (ground-based and aerial based) in addition to integrated weed management that includes chemical, mechanical, manual and cultural methods (Rao, 2021).

Precision weed management (PWM) offers a set of powerful tools to increase the efficiency of weed management by offering the following benefits:

1. Lowers herbicide costs and environmental problems, with greater weed control efficiency, leading to greater acceptance of herbicide usage.
2. Helps use of optimal quantity of management inputs on the target weeds at the right time.
3. Reduces wasteful application of inputs for better environment.
4. Delays, and even possibly eliminates, evolution of herbicide-resistant weed species.
5. Reduces accumulation of herbicide residues in soil, water and environment.
6. May possibly reduce or avoid herbicide toxicity on crops.

Artificial intelligence

The developments of information and automation technologies have opened a new era for weed management to fit physical and chemical control treatments to the spatial and temporal heterogeneity of weed distributions in agricultural fields. This review describes the technologies of site- specific weed management (SSWM) systems, evaluates their ecological and economic benefits and gives a perspective for the implementation in practical farming. Sensor technologies including 3D cameras, multispectral imaging and Artificial Intelligence (AI) for weed classification and computer- based decision algorithms are described in combination with precise spraying and hoeing operations (Gerhards *et al.*, 2022).

Convolution neural networks (CNNs)— first implemented by (LeCun *et al.*, 1989) can be used as a very precise tool for weed classification and object detection. Although the use of CNNs is relatively new, these tools have mostly replaced previous methods of AI for weed identification (Kamilaris & Prenafeta-Boldú, 2018).

Site- specific weed management has the potential to contribute to reduce pesticide use and increase biodiversity in agriculture. Both targets can be reached without causing crop yield losses and additional weeding costs in the following years. Some of the software utilized in weed detection are (Gerhards *et al.*, 2022),

- MATLAB
- TensorFlow
- Open CV
- Keras
- RGB weed detection database
- Google Net
- Detect Net
- VGGNet

(Partel *et al.*, 2019) conducted an experiment on development and evaluation of a low-cost and smart technology for precision weed management utilizing artificial intelligence. A smart sprayer was designed and developed utilizing machine vision and artificial intelligence to distinguish target weeds from non-target objects (e.g., vegetable crops) and precisely spray on the desired target/location.

Fig 1: The Smart Sprayer mounted on an All-terrain vehicle (ATV) and main components of the Smart Sprayer

This smart technology integrates a state of the art (AI-based) weed detection system, a novel fast and precision spraying system, and a weed mapping system. It can significantly reduce the quantity of agrochemicals required, especially compared with traditional broadcast sprayers that usually treat the entire field, resulting in unnecessary ap plication to areas that do not require treatment. It could also reduce costs, risk of crop damage and excess herbicide residue, as well as potentially reduce environmental impact.

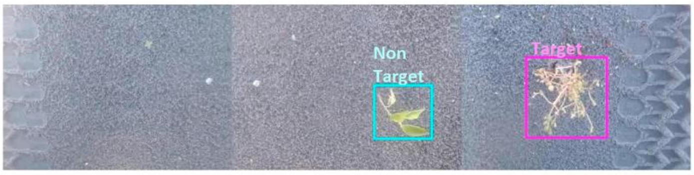

Fig 2: Smart sprayer detection on weed portulaca as target and pepper as non-target

Unmanned aerial vehicle

UAVs have become a common tool in precision agriculture. Due to their affordability, user-friendly and versatility, UAVs are often the primary choice for fast and precise in situ remote sensing or survey operations. Integrated Weed Management coupled with the use of Unmanned Aerial Vehicles (drones), allows for Site-Specific Weed Management, which is a highly efficient methodology as well as beneficial to the environment. The identification of weed patches in a cultivated field can be achieved by combining image acquisition by drones and further processing by machine learning techniques. (Esposito *et al.*, 2021).

The most important sensors available as payload are mainly categorized into three classes depending on the spectral length and number they can record:

- RGB (Red, Green, Blue) or VIS (Visible) sensors
- Multispectral sensors
- Hyperspectral sensors

UAVs used in detecting weed and herbicide application

(Hiremath *et al.*, 2023) conducted an experiment on "Comparative Evaluation of Knapsack, Boom, and Drone Sprayers for Weed Management in Soybean (Glycine max L.)". The primary objective was to evaluate the comparative efficacy of various sprayers in controlling weeds in soybeans and their work efficiency.

Pendimethalin 30% EC @ 750 g a.i ha^{-1}was used for pre-emergence herbicide application, and Imazamox 35% EC + Imazethapyr 35% WG @ 70 g a.i ha^{-1} were used for post-emergence. These treatments were tested on soybean Monocot and Dicot weed count, weed dry weight, weed index, and weed control efficiency. The sprayers were compared for time, water, labor, herbicide, and overall work efficiency.

Herbicide application was faster with the drone sprayer than with hand weeding, cultural practices, boom sprayer, and knapsack sprayer. Compared to knapsack and boom sprayers, the drone sprayer used less water and labour. Drone sprayers work most efficiently, followed by boom and knapsack sprayers.

This study focuses on the prevalence of herbicides and their impact on non-target ecosystems. It aims to develop mitigation strategies by optimizing spraying efficiency and reducing herbicide usage during pre and post emergence. The dissemination of efficient weed management practices that reduce environmental impacts and increase the efficiency of soybean cultivation.

Robotics

Combining computer vision with traditional machine learning and deep learning are driving progress in weed detection and robotic approaches to mechanical weeding. Integrating key technologies for perception, decision making, and control, autonomous weeding robots are emerging quickly. These effectively save effort while reducing environmental pollution caused by pesticide use (Zang *et al.*, 2022).

Typical site-specific weed management (SSWM) includes four processes:

1. Data collection: Use different equipment for data collection.
2. Detection: Detect weeds through proper sensors to provide real-time data such as location, area and type of weeds, or generate weed map.
3. Weeding: Choose suitable methods and pesticides for weeding according to the appeal information.
4. Evaluation: Evaluate the weeding effect for subsequent improvement.

Weed Detection Methods

As the cost of labour has increased, and people have become more concerned about health and environmental issues, site special weed management (SSWM) has become attractive. To develop SSWM, the essential first step is how to detect and recognize. Weed detection methods can be divided into two parts: machine learning (ML) and deep learning (DL). In the early stages, many scholars used traditional ML algorithms to classify weeds and crops. A typical ML-based weed detection technique involves five steps: data acquisition, pre-processing, feature extraction, and classification. (Hamuda *et al.*, 2016) reviewed recent plant image segmentation-based methods (from 2008 to 2015) and highlighted the advantages and disadvantages to colour index-based methods and threshold-based approaches.

Designing features manually requires prior knowledge and expertise, which limits machine learning accuracy improvement. Furthermore, with the substantial increase in computing power and the availability of large amounts of training data, the neural network can independently learn features and automatically optimize the weights of each layer, significantly improving DL performance (Yu *et al.*, 2019).

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