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Precision Weed Management: Modern technologies, tools and knowledge discovery

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1. Introduction:

The imperative for sustainable food production requires the integration of agricultural methods that comprehensively consider the interplay of environmental, economic, and societal aspects within agroecosystems. Crop yield reductions due to the presence of weeds, which compete with crop plants for nutrients, water, space, and sunlight, have been documented for various plant and weed species worldwide. Weeds can also act as a host for insect that attack crops as well as for disease-causing pathogens that can damage the crops. This creates added burden on farmers related to insect control and prevention of crops getting damaged by pathogens. Herbicides remain a simple and cost-effective way to control weeds but they are rapidly losing their effectiveness due to evolution of herbicide resistance. Therefore, there is a great need for a new weed management paradigm in modern agriculture based on ecological principles and nonconventional weed management approaches. Weed management is especially important in vegetable cropping system for various reasons. It affects the capital return from crops by reducing their yield, quality and market value. Automated, robotic weed control is being rapidly developed, particularly for vegetable crops and organic agriculture. Robotic weed management is a four-step process involving guidance, identification, precision weed removal, and mapping of weed species. Thermal weed control methods involve the application of heat in various forms to target and eliminate weeds.

2. Types of weed management Techniques

Weed management techniques are strategies and practices employed to control and prevent the growth and spread of weeds. The major weed management techniques are -

2.1 Weed control without using herbicides

This technique involves weeding operation either between crop rows, within crop rows, or a combination of both. Inter-row weeding using cultivators and mechanical tool involves destroying the weeds by partially or completely burying the weeds in to the soil, uprooting them, or breaking off the roots from the soils. The major limitation of cultivator type weeders is that the weeding must be done

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at the initial stages of crop growth to minimize the damage to plant due to machine-plant contact.

Mechanical Systems: Mechanical system of weeding technique uses the tools, actuators, and mechanical components that eliminate weeds or control their growth through direct physical contact with the weed plant or the soil in a single or repetitive motion. Harrowing is an old and popular technique that has been used since early ages to uproot small weeds at the early stages of crop growth. Low-cost ultrasonic sensors were also used in an intra-row mechanical weed control prototype with a rotating pinch-roller weeding mechanism for weed control in vegetable crops. The main drawbacks of mechanical weeding system are the lack of mechanism to distinguish between weeds and crop plants. These systems work best on large inter-row spacing of the crops and fail to distinguish when the spacing is narrow or when there is more infestation of weeds in between the crops.

LASER Treatment: LASER is an acronym for "Light Amplification by the Stimulated Emission of Radiation". Laser weed treatment, also known as laser weeding or laser-based weed control, is a modern and environmentally friendly method used in agriculture and landscaping to selectively eliminate unwanted weeds without the need for chemicals or manual labor. Laser treatment can kill the weeds by focusing a high energy light beam which either cuts the weed plants, burns, or stunt their growth. The effectiveness of the treatment depends on the wavelength, laser power, exposure time, and spot size. The laser weeding begins with the use of advanced imaging systems (cameras and sensors) to detect and identify the weeds based on factors like color, shape, and size. Once the weeds are detected, the laser system precisely targets each weed with a focused laser beam. Because of the precise targeting and energy control, laser weed treatment is highly selective. This selective approach reduces the need for herbicides and minimizes collateral damage. However, there are some challenges associated with laser weed treatment, such as high initial setup costs, power requirements, and the need for effective weed detection systems. Furthermore, it may not be as effective on all types of weeds and in all agricultural cropping systems.

Thermal Treatment: Thermal weed treatment, also known as heat-based weed control or thermal weeding, is a method used to eliminate unwanted weeds by subjecting them to high temperatures. A hot water treatment system developed in New Zealand used a combination of hot water (95ºC) and a foam (a mixture of coconut oil and maize oil) to kill weeds. The foam was used to provide

insulating effect which keeps the hot water in contact with the weeds for a longer time thereby increasing their effect. However, hot water treatment system has a few disadvantages as the energy associated with creating hot water and the requirement of carrying large volumes of water makes it impractical for large-scale operations, especially in water scarce regions.

The steam based weeding equipment release vaporized water which has a considerably lower water use per unit area and a higher heat transfer coefficient as compared to above discussed hot water treatment system. But the increased energy losses in steam equipment make it a far less viable alternative. Flame weeding has become more common with the increase in organic crop production and rising concerns about the effects of herbicides on human health and the environment. Flame weeding typically employs a propane or natural gas torch connected to a fuel source. This torch produces a controlled flame that can be adjusted in terms of temperature and intensity. The equipment may be handheld, mounted on vehicles, or integrated into specialized weeding machines. Flame weeding is most effective against annual weeds but windy conditions can make flame weeding challenging and increase the risk of unintended fires. Dry conditions are generally more favorable.

Robotic System: The limitations of hand weeding, mechanical weeding, and other treatments discussed above are that they require a larger gap between the rows and target only the inter-row weeds. These methods are relatively slow, inefficient, and suitable only for small-scale farm because of human dependency. This highlights the demand for robotic systems equipped with the ability to accurately detect and address weeds both within and between rows. These systems have the flexibility to employ chemical, mechanical, thermal weeding techniques, or a combination of these methods. Robotic weed management is a four-step process involving guidance, identification, precision weed removal, and mapping of weed species. The feasibility of a robotic weed control system depends upon accurate machine vision analyses, robotic efficiency and suitability, variable-rate-application technology, decision support system, and strength of weed-sensing tools.

2.2 Weed control using herbicides

weed control using herbicides is a common and widely practiced method for managing unwanted vegetation in agriculture. Herbicides are chemical substances specifically designed to kill or inhibit the growth of plants, including weeds. Precision

spraying of the herbicides is the most widely used implementation because of its targeted application and has higher reliability as compared to previous methods. The major issue with this technique is the detrimental effect of the applied chemicals on the environment and human health. Therefore, most advanced weed control techniques are trying to optimize the amount of spraying to achieve the overall reduction in herbicides.

Conventional herbicide treatments: The conventional method of herbicide treatment involves the application of same quantity of herbicide throughout the field irrespective of the weed distribution. The chemical application could be either soil application or foliar application. Soil application includes surface application where top layered weed plants are targeted, sub surface application where chemicals are applied to the sub-layer of soil, and band application for crop rows. Conventional herbicide treatment requires comparatively less initial investment in equipment or machinery than precision weed management system. The major disadvantage is the excessive use of chemicals which result in higher operational cost, more environment pollution, and crop damage.

Precision weed management technology: This technique uses automation and modern technology advancements (Robotics, machine vision, HD cameras, and processing power) to optimize the use of resources with variable rate application. Precision weed management practices use targeted spraying as opposed to the conventional spraying methods which are either blanket sprayer for inter-row spraying or need human interference for intra-row applications.

Components of precision weed sprayers: The basic components of any precision weed sprayers are-

- **Sensing unit:** This unit includes a camera or sensor that captures image, identify the location, and types of weed and plants, and relay the digital information to the processing system which could be based on image processing/machine learning/deep learning or combination of these.
- **Management model:** It uses the information from decision-making algorithm, crop-weed population dynamics and optimize the treatments based on the type, density, and location of the weeds.
- **Spraying system:** It triggers the specific nozzle based on the information coming from the sensing unit and decision-making algorithm.
- **Driving unit:** The weed sprayer, sensing unit, and all the electronics

hardware are either attached to an autonomous/semi-autonomous robot or farm tractor.

Vision system: Weed detection using computer vision technology can be broadly categorized into two methods-

- Detection using image processing methods
  - Shape extraction
  - Texture extraction
  - Spectral feature extraction
  - Color extraction
- Detection using object detection algorithms and deep learning methods
  - CNN-based weed detection
  - Non-CNN-based weed detection

3. Conclusion:

Although non-herbicide-based weed control system may be safer for the health and environment, they have their unique challenges and limitations that restrict their wide spread adoption. The majority of the systems don't have an efficient mechanism to differentiate between weeds and crops. Most of the mechanical weeders that employ harrow requires require multiple passes and work best only on softer soil conditions. Laser treatment to kill weeds requires it to be applied at an early stage to be effective. Also, it could damage the plastic covers if used on crops grown on raised beds with plastic cover.

The advancement in machine vision and machine learning have increased the detection accuracy and processing speeds. However, even the top deep learning algorithm also have their disadvantages in terms of the requirement of the large datasets for training, the cost associated with data annotation, higher memory requirements, and slower training speeds. Dataset collection also presents a few challenges related to data quality. To achieve higher accuracy, the dataset needs to have a high percentage of data that closely resembles the actual test conditions expected in the field. More work needs to be done to conduct actual field trials on raised beds and crop rows with the weed management systems to better gage the adaptability of these systems to real-life conditions.