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Precision Weed Management Technique: A Smarter Way to Manage the Weed

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Abstract

In conventional agriculture, we supplied agrochemicals consistently across production areas in order to control weeds, which led to excesses in some areas and insufficient intervention in others. One of the root causes of pollution is an excessive application of agrochemicals used in excess and persists in the soil, leached down into groundwater, and/or drain into bodies of surface water. Both the ecosystem and human health could be at risk by this circumstance. Since the 1960s, agrochemicals' buildup and long-term toxicity risks in food and water have been observed. Agrochemical contamination and pollution of soil, groundwater, and run-off can result in a variety of ailments, including nervous system disorders. As a result, enhanced management techniques that minimize the over-application of agrochemicals have emerged as an important domain of research. 'Precision farming' is a possible approach for lowering chemical inputs. Precision farming, commonly referred to as site-specific farming, permits farmers to manage the field at a very precise spatial resolution and can hence boost the efficiency of farming. With the motive of applying control measures where and when they are required, a number of precisions weed management (PWM) methods are being developed to scout and detect weeds. We hypothesized in this review that Robotic technology and site-specific weed management are the measures will be effective in controlling weeds in the cropland, pastures, grasslands etc.,

Keywords: Precision Weed Management; Agriculture, Chemicals

Abbreviation: UAV: Unmanned Aerial Vehicles.

Introduction

The reduction in crop yield and quality is mainly contributed by weeds [1]. Weed generally competes with crops when it comes to nutrition, water, and sunlight. In India, weed losses will likely go over 11 billion USD annually, ranging from 13.8% in transplanted rice to 76% in soybean including the greatest potential loss emanating from weeds (34% of all biotic stressors), followed by insects (18%) and diseases (16%) [2]. In comparison with crops, weeds have higher levels of morphological, physiological, and anatomical plasticity, making them more resilient to environmental stressors [3]. Weeds and other biological components can interact negatively, and can damage surrounding crops [4]. Herbicide residue-containing weed might therefore result in accumulation of off-flavour products [5], or, in certain cases when they get into the food chain, they become harmful for humans as well as animals [6]. The potentially harmful substances could lead to hepatic failure in both human beings and farm animals if ingested [7].

Herbicides disperse from the target plants in a variety of ways, bringing about environmental pollution. Herbicides adhere to soil particles through the sorption process, severely polluting the soil [8]. Herbicide delivery to field drains or seepage into deeper soil layers could heighten herbicide losses in target crops and pollute the groundwater as well as the surface water. The biodiversity of above and below-ground residing forms, including flora, animals, and microbes, may be threatened as a result, resulting in soil and water contamination [9]. The process of environmental recycling between the atmospheric and terrestrial environments is accelerated up by the airborne drift of herbicides utilised in agricultural practises, as well as the volatilization, dispersion, and transportation of their residues across considerable distances. However, this process leads to air pollution in the surrounding area and has a negative influence on the environment globally [10]. Thus, in order to reduce and eventually eradicate the ecological, environmental, and possibly societal issues associated with the widespread usage of herbicides, alternative weed mitigation measures must be developed and promoted. Herbicide spraying is one of the most frequent weeding techniques used globally [11]. Herbicides are routinely sprayed over a field consistently, regardless of the amount of weeds present, which causes over spraying in weed-free areas. The aforementioned approach of weeding results in waste of herbicides and degrades the agricultural ecosystem. To address these issues, the site-specific weed management (SSWM) approach was proposed [12]. SSWM is an approach that involves managing weeds differently within a crop field to account for variations in the density, location, and makeup of the weed population [13].

In crop fields, weed populations are frequently scattered irregularly. As a result, the base of this control strategy is to set up a guideline of weed spatial information to apply herbicides with a minimum consumption by adapting it to actual needs and utilising other techniques, including any use of plant derivatives that comprises of allelopathy effect, such as natural herbicides in order to minimise agrochemical pollution [14]. Soil, water, and air pollution are all reduced as an outcome. By experiencing these advantages, smart farming's comprehensive and resource-efficient approach to herbicide spraying with SSWM reduced herbicide consumption by 40% to 60% [15]. Accordingly, increased environmental protection, sustainable agricultural output, and expanding economic profits can all be achieved. Weed detection and mapping come first in the implementation of an SSWM strategy. Combining the sensor, processing techniques and actuation system together, and this objective entails developing a weed map. Images of weeds or other non-imaging type of data can be obtained using on-the-ground or remote sensing technology.

Precision Weed Management

It is a technique that adjusts management of weeds within a crop field by taking into account variations in the location, density, and makeup of the weed population [16]. The aforementioned concept is supported by three facts: (i) The distribution of weed populations within crop fields is often irregular, (ii)Weed detection and mapping techniques have been made possible by new sensors and platforms combined with geospatial technology like GPS and GIS and (iii) New smart sprayers, robots and mechanical cultivators have brought about the opportunity for thorough weed management tailoring to match the various conditions encountered in each field [17,18]. Site-specific weed management has a real potential to deliver a more productive and sustainable agricultural production based on a more precise and resource-efficient approach. Like the majority of other crop, soil, and pest management techniques, weeds management inputs are often distributed consistently across the entire field. However, the occurrence and intensity of weeds vary widely across the field. Due to numerous of agro-ecological conditions, they are most often uneven and patchy (aggregated or clumped). Thus, using herbicide uniformly across a field where the target weeds are not evenly dispersed is potentially a waste of resources. This could result in serious financial, social, and environmental consequences about the usage of herbicides. In spring barley cultivation, Gerhards, et al. [19] observed herbicide savings for dicot and monocot weeds of 60% and 92%, respectively, and for similar weed groups in maize of 11% and 81%. In general, only 7% to 64% of the entire area requires herbicide application, indicating a potential for herbicide cost savings. Many weed scientists have been motivated to do research on more effective weed management strategies by the spatial heterogeneity of weeds and the potential for a reduction in the quantity of herbicides utilised. Precision weed management is one of these strategies. The following advantages have been offered by PWM, which provides a set of robust tools to boost weed management efficiency:

1. Increases weed control efficiency while decreasing herbicide costs and related problems with the environment, which increases public acceptance of herbicide use.
2. Facilitates in the timely application of the best possible amount of management inputs to the target weeds.
3. Lessens the use of resources inefficiently for a better ecosystem.
4. Minimizes the build-up of herbicide residues in the environment, water, and soil.
5. May lessen or prevent the toxicity of herbicides on crops.

Weed Monitoring

There are two ways for accomplishing this task: (i) creating a weed map and utilising it for future weed control operations, or (ii) Real time weed detection while integrating the sensor, processing steps, and actuation system. Both on-ground and remote sensing platforms can be used to collect weed images or non-imaging records.

Weed Detection Techniques

It is possible to further enhance the system's accuracy and sample point density by detecting weeds through automation. Mainly three approaches were used to detect the weeds under automation, they are:

1. Biological morphology: determination of the plant species' shape and structure.
2. Spectral characteristics: recognising a plant based on its reflectance's. For such purposes, hyper spectral or pixel-based classifiers are being used.
3. Visual texture: recognition based on the colour and greyscale calculation values of the images.

Weed Control Technologies	Method	Drawbacks	Remarks	References
Precision spray systems	Autonomous robot	N.A.	Sprays targets autonomously and with remarkable accuracy.	Sogaard, et al.
Hyperspectral imaging sensors	A hyperspectral imaging system linked to a heated oil application mechanism using microspray	A multi-season calibration process is required.	Spray application for various herbicides based on weed species is customizable.	Zhang, et al. [20]
Weed sprayers	Machine vision weed spotter	N. A	With greater than 90% accuracy, distinguishes weed leaves from maize plants.	Kargar, et al. [21]
Automatic weeders	Robovator	It can only distinguish between small and large plants.	Removes 95% of weeds.	Mia, et al. [22]
UAV's	UAV and GPS technology integration	Some technology literacy is required.	Fast and precise in situ remote sensing or survey operations.	Esposito, et al. [12]

Table 1: Overview of precision weed control technologies.

GPS Controlled Patch Spraying

The majority of patch spraying was carried out using georeferenced weed maps. In places where weed infestation levels exceeded the economic weed threshold, herbicides were sprayed and in locations with minimal weed infestations, boom sections were turned off. This approach saved 23-89% of herbicides in cereals, maize, sugar beet and peas [17,19,23,24]. Reduced herbicide rates were used in areas with smaller, less troublesome weeds that are more sensitive to herbicides, which also brought about cost savings [25]. There were no lower yields in the unsprayed regions than in those areas with treatment, and there were no additional weed management expenses in the years afterwards [26,27]. Savings were even doubled if the variation of the distribution of weed species was taken into account and each weed species group was treated separately with various herbicides utilising a GPS-controlled multiple-tank sprayer [28]. Such results highlight the great herbicide-saving potential of patch spraying. Patch spraying further reduced the amount of herbicide released into the environment and the danger of herbicide residues in water and the food chain. It also minimised the selection of populations of weeds resistant to herbicides [29,30]. To safeguard weed species that are rare and endangered, Jensen and Lund used patch spraying algorithms. Where rare weed species were detected or mapped, the sprayer was turned off [31]. Despite these advantages, patch spraying's adoption into actual farming was slow due to numerous technical limitations. Spraying systems, in particular, do not permit adjusting the herbicide mixture in accordance with weed distribution maps. Patch spraying demands additional effort in terms of data collection and documentation. The farmer will also need to plan and predict the application of two or more herbicide solutions, each of which will target different weeds or groups of weeds. Herbicide savings are quite likely with the right planning and expertise, but the financial advantages might disappear owing to maintenance costs or poor planning and programming [17,32]. The majority of patch spraying systems were offline up until the early 2000s [16]. Weed mapping and patch spraying were made easier by the use of unmanned aerial vehicles (UAV) for weed sensing [33]. In comparison to near-ground camera mapping, UAV systems were able to map and georeferenced the distribution of perennial weed species like *Cirsium arvense* for a lesser cost and more effectively [34]. However, weed mapping had to be done before patch spraying, and the sprayer's board computer had to be loaded with georeferenced application maps [32]. Real-time weed/crop classification in digital photos utilising more complex algorithms was not possible since computer processors were not fast enough [35,36] in maize developed the first real-time patch spraying system based on weed coverage data from digital photographs.

Success of SSWM Relies on Crucial Elements

1. A tool for precision weed control that includes the use of a sprayer with individual controllable boom sections or a network of nozzles that allows for spatially varying application of herbicides.
2. A weed detection system that identifies localizes, and measures crop and weed parameters.
3. A model for managing weeds that aids in the application of knowledge and data on crop-weed competition, population dynamics, the biological efficacies of control measures, and algorithms for making decisions, and optimises treatments in accordance with the density and species diversity of weeds.
4. The heterogeneous agro-ecosystem, which includes individual crop and weed plants, is another crucial component of SSWM technology. These could be individual plants in small groups, clusters or patches within a field, or they might represent an entire field. As stated by Christensen, et al. [17], a farm's spatial resolution may indicate a hierarchy of weed management at four different levels:

- Use accurate spray nozzles, controllable mechanical tools, or laser beams to treat individual plants.
- Treatment of a grid that is resolution-appropriate e.g. using a nozzle or a hoe unit to adjust the spray.
- Use weed plant clusters to treat weedy patches or subfields.
- Treat the entire field uniformly

Recommendation of Site-Specific Weed Management

- Patches of new or difficult-to-control weeds can be controlled to stop them from taking over the entire field.
- Farmers are able to locate weed patches in fields by scouting them out or by employing remote sensing or aerial photographs.
- Patches can be managed through GPS guided systems, localised spray operations, or weed-sensing sprayers (in fallow).
- Additionally, non-chemical techniques like mowing, tillage, cutting for silage, or grazing is effective ways to control weed patches.

Crop/Weed	Platform/sensor	GSD (m)/ Area (ha)*	Phenology stage of crop	Weed detection procedure†	References
Sunflower	Airborne/RGB + NIR	0.50/29	Flowering	Spectral angle mapper (SAM)	Pena-Barrag, et al. [37]
Sinapis spp.	RGB + NIR		Vegetative, Mature	BDVI	de Castro, et al. [38]
Maize, sunflower/ several weeds‡‡	UAV††/RGB	0.014/1.0	Seedling	OBIA	Perez Ortiz, et al. [39]
Barley/Cirsium arvense,	UAV††/RGB	<0.02/0.2	Mature & Seedling	ExG vegetation index (pixel-based)	Rasmussen, et al. [33]
Wheat/Avenasterilis	RGB + NIR	2.40/3000	Mature	OBIA	Castillejo Gonzalez, et al. [40]

‡‡The sunflower field was infested by *Amaranthus blitoides, Sinapis arvensis* and *Convolvulus arvensis*, whereas the maize field was infested by *Salsola kali.*

Table 2: Information on relevant studies on remotely sensed weed detection and mapping.

Crop/Weed	Sampling area	Technique	Phenology stage of crop	Classes	Sensor	References
Wheat/various weeds**	55 x 42 cm	Red/Infrared imaging	Seedling	Grasses/broad leaves	Bi-spectral camera	Peteinatos, et al. [41]
Wheat, triticale, rye barley,	518 x 2.5 cm	Spectral imagining	Early stage	Bare ground/weeds	Optoelectronic	Dammer, et al. [42]
pea/various weeds*						
Maize/various weeds††	10 000 cm^2	3D imaging	Vegetative	Crop/grasses/broad leaves	RBG	Andujar, et al. [43]
Maize/various weeds¶	300 cm long	Laser imaging	Vegetative	Crop/grasses/broad leaves	LiDAR-TLS	Andujar, et al. [44]

* *Chenopodium album, Viola arvensis, Agropyron repens, Lamium spp., Sorghum halepense, Datura spp., Xanthium strumarium, Cyperus rotundus*
††*Sorghum halepense, Datura ferox, Salsola kali, Polygonum aviculare, Xanthium strumarium.*
***Alopecurus myosuroides, Veronica persica, Matricaria chamomilla.*

Table 3: Information on relevant studies on ground-based weed detection and discrimination.

Weed	Sensor	Herbicides	Accuracy (%)	References
Palmer amaranth	Raman spectroscopy	Glyphosate	78-83.99	Singh, et al. [45]
Kochia	Resonon Pika IIg	Dicamba, glyphosate	66.0- 81.0	Nugent, et al. [46]
Italian ryegrass	Hyperspectral camera	Round-up	72-85	Lee, et al. [47]
Water hemp	Thermal camera (Infrared Camera Inc.)	Round-up	87.92–91.99.0 (Drone	Shirzadifar, et al. [48]
Ragweed	Hyperspectral camera	Round-up	950–99.99	Shirzadifar, et al. [48]
Lambs quarters	Hyperspectral camera	Dicamba	24.93.0–78.67 (Drone)	Nugent, et al. [46]
Palmer amaranth	Resonon Pika II	Round-up	94.01.0–96.90	Reddy, et al. [47]

Table 4: Spectral sensors for herbicide-resistant weed detection [49-51].

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