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Drone Technology: The Future of Weed Management

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Abstract

In agriculture production system, weeds are the undesirable plants that can significantly reduce the crop yield by competing with crops for natural resources. Therefore, timely weed management is crucial for higher crop productivity. Different methods are practiced to control weeds *viz.,* cultural, physical, chemical, machines, artificial intelligence and sustainable strategies. Among all those methods, chemical method is mostly adopted in crop production for effective management of weeds. Conventionally, the herbicides are applied through knapsack sprayer. However, it encompasses several limitations such as scarcity of farm labour and high risk of exposure to herbicides, which affect the human health. Moreover, knapsack sprayer consumes more time, labour, water, energy and toils for herbicide application. To reduce the excess use of resources, drones are the alternative option for herbicide application, which requires less resource. A drone is also equipped with a camera and various sensors. These can be used to identify areas where weeds are growing and to control weeds in a site-specific manner. Therefore, by using a drone for weed control, it is possible to reduce human labour, time, energy and herbicides, while reducing environmental pollution and ensuring sustainable weed management.

Keywords: Drone, Energy saving, Site-specific herbicide application, Sustainable weed management

Introduction

Weed management is a significant part of crop production because weeds are competed with the crop plants for water, nutrients, light and space. If weeds are not controlled at the right time, they cause substantial yield loss. In this above situation, herbicide is most effective and economic feasible method of weed management strategies. However, method of application of herbicide significantly reduced the efficiency of weed control and also safety of the operator. Knapsack spraying is commonly used in many farming situations. However, it requires the operator to carry a filled spray tank and move through the crop. This makes the operation laborious and time consuming, particularly in large fields, muddy soils and tall crops. But, maintaining a constant walking speed, even spray coverage and spray height are challenging during manual spraying. Regular exposure of pesticides can cause health problems on operator. These limitations have created attention in alternative methods that can make herbicide application easier, faster and more precise (Gupta *et al.*, 2022). For that, drone technology is an efficient way of herbicide application method, which requires less water, time, labour and energy than conventional spraying method.

The use of drones for herbicide application has multiple advantageous (Figure 1). Apart from the herbicide spraying, it's equipped with camera and various sensors which is used for crop monitoring (Esposito *et al.*, 2021). RGB cameras in drone to capture image based on spectrum visible colour and multispectral sensors gather information from various wavelength region that can help distinguish weeds from crops. Hyperspectral sensors offer detailed spectral information which is used for identifying plants with similar appearance. Images from camera cansed to define weed distribution and make weed distribution map of fields for identification of precise location of the weed patches. This is essential because weeds grow unevenly across the field.

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Several weeds have heavy infestation, while other areas may remain less infestation or weed free. Therefore, weed map provides an opportunity to identify the actual location of weed and use this information for site-specific herbicide application. The appropriate combination of the sensor and sprayer will help in implementing the needs-based approach from general practice. It will also help in reduced work force, decreased spraying time, reduced fuel requirement, decreased production costs and at the same time prevent the misuse of chemicals (Zhang *et al.*, 2024).



Figure 1: Advantages of drone in herbicide application

Role of Drones in Modern Weed Management

1. Drone-based Weed Mapping

Drone-based weed mapping provides a clear view of weed distribution within a field. High-resolution images can be used to identify weed-infested areas and prepare digital weed maps. These maps help in identifying the areas where weed control measures are required.

2. Site-Specific Herbicide Application

Weed distribution mapping helps to identify areas with low, medium and high weed populations in a field. Based on weed populations and weed infested area, the drone can spray herbicides only to the required areas. This approach helps to reduced herbicide quantity, labour, spray volume, chemical drift and operation cost. Thus, the site-specific weed management can improve herbicide use efficiency and contribute precise and sustainable weed management.

3. Lower Labour and Spraying Cost

Drone spraying can cut down on the physical effort required when compared with traditional backpack spraying since the operator need not carry a full sprayer and have to walk through the crop. It also reduced the labour requirement by 50%, application cost by 18% and total cost of weed management by 13%. These savings are particularly useful in circumstances where labour is scarce and timely weed control is important.

4. Energy Saving through Drone Spraying

Conventional knapsack spraying requires a person to carry the spray tank and walk through the field, which needs more human energy and labour. In contrast, the drones operate with a battery and flies across the field, it doesn't need to walk the entire field. Therefore, drone-based weed management can reduce 25-57% input energy and 88-94% reduced spray volume over conventional spraying.

5. Reduced Chemical loss and Environmental Impact

It is possible to avoid treating areas that are free from weeds when herbicide is applied only to the areas infested with weeds. This helps to reduce the wastage of chemicals and lowers the risk of herbicide application in non-target areas. Under appropriate conditions of weed distribution, site-specific application can cut herbicide use by about 40-70%. The lower use of chemicals may also help to reduce the environmental impact associated with unnecessary pesticide application.

6. The Use of Drones in Weed Control for Sustainable Management

The significance of drones doesn't end with faster spraying; their combined advantages in terms of weed mapping, precise application, saving labour, saving energy and reducing the use of chemicals make them suitable for sustainable agriculture. Making better use of inputs allows unnecessary spending to be avoided while at the same time keeping effective weed control. Drone technology can become an important part of integrated and sustainable weed management when used in conjunction with crop rotation, mechanical methods, cultural practices and the proper use of herbicides (Roslim *et al.*, 2021).

Challenges and Limitations of Drone-based Herbicide Application

1. Cost is a major issue: The cost is a major concern since a spray drone requires a big initial outlay for the drone itself, the batteries, the charger and the spraying device.

2. Battery limits field operation: A drone cannot carry out spraying for a long time with a single battery, particularly when the area to be treated is large.

3. High Wind speed can affect spray deposition: Wind speed and direction may cause the herbicide droplets away from the target area, resulting in uneven spray coverage and herbicide drift on non-target crop.

4. Correct spray settings are important: The drone must have the correct nozzle, droplet size, spray pressure flight speed and height. Adjusting these settings can improve herbicide efficiency, so if these settings are not correct, it leads to poor weed control.

5. An incorrect weed map can cause improper spraying: If a patch of weeds is overlooked during mapping the area might not get the herbicide; on the other hand, if a crop area is wrongly identified as a patch of weeds unnecessary spraying may result.

6. Herbicide choice cannot be ignored: The herbicide, its formulation, the dose and the spray volume must be

appropriate for use by a drone and for the specific crop. Simply changing the recommendation that would have been used with a knapsack sprayer to one for drone spraying is not sufficient without first carrying out a proper evaluation.

7. Crop and weed stage influence control: The effect of the crop and weed growth stage is that it is hard to spot very small weeds, while more mature weeds need a higher degree of spray coverage; also, dense crop growth can stop the droplets from getting to the weeds growing beneath the canopy.

8. It is necessary to be skilled: Effective spraying relies on proper handling of the drone, correct calibration, careful flight planning, the right mixing of the chemical and safe operation. Failure to receive adequate training can have an effect on both the quality of the spraying and on the safety of the operator (Daramola *et al.*, 2026).

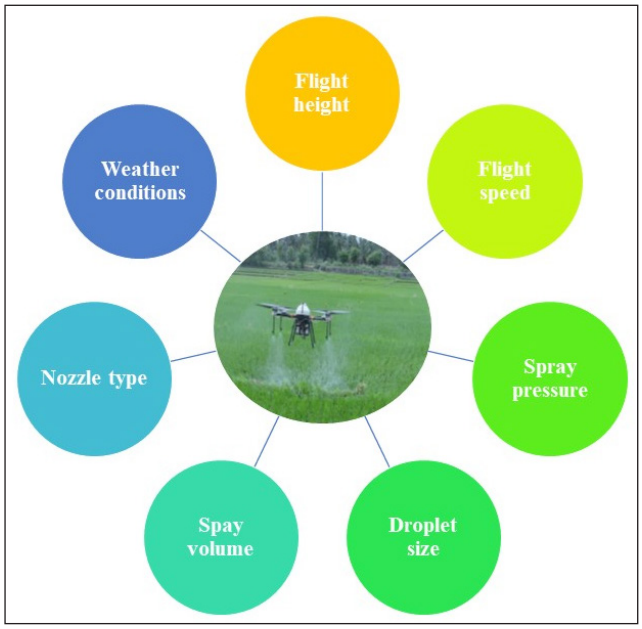


Figure 2: Key parameters influencing drone-based weed management

Conclusion

Drone based herbicide application offers a precise and effective method to weed management. It can reduce herbicide wastage, labour, spray volume, over conventional spraying. However, suitable weather condition and proper spray setting are crucial for effective weed management. Hence, a drone can be a valuable tool for future sustainable weed management.

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