Recent Advances in Herbicide Application Techniques and Methods: A Review

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ABSTRACT

The continuous evolution of herbicide application techniques is essential for improving weed control efficacy, reducing environmental impact, and ensuring agricultural sustainability. Recent advancements have focused on precision application technologies, smart sprayers, drones, and novel formulations that enhance herbicide effectiveness while minimizing off-target effects. This review explores the latest developments in herbicide application methods, including precision spraying, site-specific weed management, unmanned aerial vehicles (UAVs), and advanced formulation technologies. These innovations contribute to sustainable weed management by reducing herbicide use, improving targeting efficiency, and mitigating resistance development.

INTRODUCTION

Weeds had been present as long as the nature had prevailed. In current scenario of agricultural production weeds pose as a challenge to achieve higher yields to satisfy the current increasing demands for food security. Weed account for 37% of agricultural yield loss in India (Yaduraju, 2006). Hence, it becomes important to address the hurdle with introduction of herbicides that are efficient in killing those

unwanted plants. The conventional method of herbicide application such as broadcast spraying, often result in excessive herbicide use, drifts and leading to environmental concerns and herbicide resistance.

Weed management remains a crucial aspect of agricultural production, directly impacting crop yield and farm profitability. Conventional herbicide application methods, such as broadcast spraying, often result in excessive herbicide use, leading to environmental concerns and herbicide resistance (Shaner, 2014). In response, researchers and industry stakeholders have developed advanced application techniques that improve efficiency and sustainability. This review highlights recent advancements in herbicide application technologies and their potential implications for modern agriculture.

1. Precision Herbicide Application

Precision agriculture technologies have revolutionized herbicide application by enabling targeted and efficient weed control. Key advancements in this area include:

1.1 Site-Specific Weed Management (SSWM): SSWM uses weed mapping to identify areas with weed densities below thresholds, then it adjusts herbicides rates based on local weed species and densities. In case, there are areas below economic threshold it turns

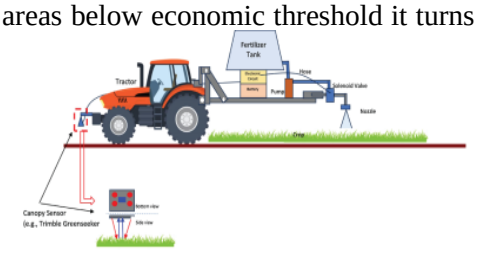

Fig.1. VRT using sensors for application of fertilizers

off the herbicide booms. To reduce further herbicide consumption, it uses species specific spraying. Studies have demonstrated that SSWM can reduce herbicide use by up to 50% without compromising weed control efficacy (Lati *et al*., 2016). Use of SSWM can save up to 23-89% on herbicide costs (Roland *et al*, 2022).

1.2 Smart Sprayers and Variable Rate Technology (VRT): The Variable Rate Technology (VRT) enables the farmers and their agronomic advisors to apply agricultural inputs—like water, nutrients, and chemicals—at varying rates that adjust to the spatial variability of the field. VRT can also be integrated to irrigation, seeding, fertilization, and fungicides application. Proper usage of this technology can benefit through less use of herbicide, more net farm income, reduce input and labor cost, and minimizing the risk of environmental degradation. Research has shown that VRT can significantly reduce herbicide runoff while maintaining effective weed control (Christensen *et al*., 2021).

2. Drone-Based Herbicide Application

Herbicide is applied by the help of Unmanned aerial vehicles (UAVs). This method proves to be efficient in covering large area in short span, preventing crop injury due to less drift hazard, requiring less quantity of herbicide as compared to conventional method and time saving. Addition of advancements such as robots, artificial intelligence and sensors help in optimization of weed detection and eradication leading to improved outcomes.

TYPES of DRONES

Primarily there are two types:

Fixed wings: They are like airplanes, and use lift and drag to stay in the air.

Fig.2. Fixed wings drones

Rotary drones: These drones have multi-rotary wings, which allow them to change angles and run at lower heights. They are more easily operated than fixed-wing drones.

Fig.3. Rotary drones

Under pre-emergence (PE) spraying, drones can achieve a 98% to 100% weed control efficiency in farm fields with low straw and high soil moisture. The use of drones for pre-emergence spraying must be given priority because of their increasing role in weed control. (Meesaragandla *et.al*, 2024). Studies have shown that UAV-based spraying can achieve a 30% reduction in herbicide use while maintaining comparable weed control effectiveness (Wang *et al*., 2019).

3. Electrostatic and Ultra-Low Volume (ULV) Spraying

Electrostatic ultra-low volume (ULV) spraying is a method of depositing a low volume of liquid on a surface utilizing an electrostatic charge that attracts the droplets, thereby producing an even spread and minimizing wastage. It is commonly used in pest control activities, e.g., for mosquito control, where a high-quality spray is required to ensure better contact with the target pest.

Electrostatic sprayers have been found to improve herbicide efficiency by up to 40%, reducing environmental contamination (Matthews, 2018).

4. Controlled-Release and Nano-Formulated Herbicides

Recent innovations in herbicide formulations focus on improving efficacy while reducing environmental impact:

4.1. Nano-Herbicides

Nano-herbicides are produced by nano-based particles used in the synthesis of herbicides and, alternatively, by efficient use for herbicide synthesis by nano particles-based delivery system. The benefits of nano-herbicides include reduction in the amount of synthetic chemicals, efficient delivery system, safety of personals, and efficient reaction time. Nano-herbicides are a new technology to overcome all the drawbacks of conventional herbicides. One of the largest issues of conventional herbicides is the resistance of weeds which needs a strategic plan to eradicate it. Nano-herbicides with properties like increased penetration ability and efficient delivery system can be efficient to decrease such issues (Patil-Patankar et.al, 2022). Studies indicate that nano-herbicides can reduce the required application rate by 20–30% while maintaining effectiveness (Shah *et al*., 2021).

4.2. Encapsulation Technologies

Nanoencapsulation of herbicides is a delivery system where an active ingredient is encapsulated with different materials of nano range sizes and delivered in a controlled manner for attaining season long weed free state. Nanomaterials that are synthesized from biopolymers are highly soluble in suspension and bear more surface area enhance targeted activity (Muchhadiya *et al*.,2022). Nano encapsulated herbicides are slow releasing making effective in controlling weed population under budget (Sousa *et al*.,2018). Encapsulation technology has shown potential in extending herbicide activity duration while

minimizing off-target effects (Kumar *et al*., 2020).

5. Challenges and Future Prospects

Despite significant progress in the field of herbicide applications for enhancing the efficacy and minimizing the inputs there are several challenges that comes for the adoption of such methods:

- High initial costs of precision agriculture equipment
- Limited accessibility of technology for small-scale farmers
- Need for regulatory frameworks for drone and nano-herbicide use

Future research should focus on improving cost-effectiveness, increasing farmer awareness, and developing more sustainable herbicide formulations to minimize resistance issues.

CONCLUSION

Recent advancements in herbicide application techniques have significantly improved efficiency, precision, and sustainability. Technologies such as UAV spraying, AI-assisted weed management, and nano-herbicides are revolutionizing weed control strategies. Continued research and adoption of these innovations will be critical for reducing herbicide reliance while maintaining agricultural productivity.

REFERENCES

Christensen S, Søgaard H T, Kudsk P, & Jørgensen R. N (2021). Site-specific weed management using precision spraying technology. *Weed Research*, 61(2), 132–145.

Kumar S, Verma R, & Singh P (2020). Encapsulation techniques for controlled release of herbicides. *Journal of Agricultural Chemistry*, 45(3), 225–240.

Lati R N, Filin S, & Eizenberg H (2016). Site-specific weed management using multispectral imaging. *Precision Agriculture*, 17(4), 471–487.

Matthews G A (2018). Electrostatic spraying for improved agrochemical application. *Pesticide Science*, 54(3), 145–152.

Meesaragandla, S, Jagtap M P, Khatri N, Madan H, & Vadduri A A (2024). Herbicide spraying and weed identification using drone technology in modern farms: A comprehensive review. *Results in Engineering*, 101870.

Patil-Patankar V, & Sanghvi G. (2022). Nanoherbicides: A sustainable option for field applications. In *Relationship Between Microbes and the Environment for Sustainable Ecosystem Services, Volume 1* (pp. 335-355). Elsevier.

Shah, R U, Javed A, & Riaz M (2021). Nano-herbicides: Advances and future prospects. *Environmental Science and Pollution Research*, 28(5), 3056–3070.

Sousa G F M, Gomes DG, Campos EVR, Oliveira JL, Fraceto LF, Moreira RS *et al*. Post-emergence herbicidal activity of nanoatrazine against susceptible weeds. *Front. Environ. Sci*. 2018;6:12.

Wang J, Zhang H, & Li Y (2019). UAV-based herbicide spraying for precision agriculture. *Agricultural Engineering International*, 21(2), 98–112.

Yaduraju N T. Herbicide resistant crops in weed management. In: *The extended Summaries, Golden Jubilee National Symposium on Conservation Agriculture and Environment.* Octo., 26-28, Banaras Hindu University, Varanasi. 2006; pp 297-98.