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Spray Pattern Optimization for Effective Plant Protection

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Introduction

Spray pattern optimization in agriculture refers to the process of optimizing the way fluids are dispersed from agricultural vehicles, such as sprayers, to achieve maximum efficiency and effectiveness in crop protection and fertilization (Indu et al., 2022) . This optimization involves considering factors such as vehicle travel speed, direction, wind speed, wind direction, and the heights of nozzles from the ground surface (Soelaksini et al., 2018). By using sensors and a controller, the spray pattern on the ground surface can be computed based on the fluid dispensed through the nozzles, and any overlap between spray patterns can be identified (Shariq Kamal et al., 2014). Corrective actions can then be taken, such as adjusting the vehicle's travel speed or the duration of time the fluids are dispensed, to ensure optimal coverage and minimize waste (Jain et al., 2021). This optimization process helps to improve the accuracy, efficiency, and cost-effectiveness of spraying activities in agriculture.

Spray pattern optimization is important for effective plant protection because it improves the efficiency and quality of aerial spray operations, reduces the pollution caused by chemical pesticides, and ensures high-quality, efficient, and environmentally safe chemical plant protection (Zhang et al., 2021). The spray parameters, such as flight height and flight velocity, significantly influence the effective spray width, droplet density, and droplet deposition uniformity (Zhang et al., 2021). By studying and determining the optimal spray parameters, such as flight height and flight velocity, the usage of pesticides can be minimized while still achieving effective plant protection (Hu et al., 2021).

Factors that affect spray pattern include the flow characteristic of the atomization gas, nozzle configurations, spray parameter settings, and fluid pressure in the nozzle (Martin & Latheef, 2022) (Tillmann et al., 2018). Optimizing spray pattern has several benefits, such as determining the produced coating thickness in arc spraying processes, managing spatial and temporal variability in agricultural ecosystems for effective pest management (Huzjan et al., 2023), and improving engine efficiency, combustion process, and gas emissions in engines with internal combustion. Additionally, optimizing spray pattern can help in achieving accurate spray distribution, reducing water consumption, and increasing spray distribution accuracy. It also plays a crucial role in the air engulfing and mixing process, which affects the overall performance of the spray system.

Types of spray patterns (ICAR, 2019)

- **Nozzle:** A sprayer's nozzle is a crucial part that divides the liquid spray into the appropriate size droplets, regulates the rate of application, directs the spray in an appropriate direction, and ensures that the pesticide is applied thoroughly and safely. Nozzles consist of the following main components: body, disc, washer, valve, and cap. The supply pipe or nozzle itself may have a shut-off. A minimum hydraulic pressure of -75 kPa is needed for the majority of these nozzles, while a hydraulic pressure of 300 kPa is needed for the full development of the spray pattern.
- **Flat fan nozzles:** Herbicides are sprayed using flat-fan nozzles, which have a flat sheet-like spray pattern and low operating pressure. For even spray dispersal, the spray pattern is designed to allow for 30–50% overlap.
- **Hollow cone nozzles:** In field crops, hollow-cone nozzles are typically employed to spray insecticides and fungicides when thorough leaf surface coverage and foliage penetration are sought. The spray pattern is circular with tapering edges that create a hollow cone or ring to ensure that insecticides are adequately covered from all sides. The liquid emerges as a hollow, conical sheet that breaks into small droplets. Because hollow cone nozzles create smaller droplets than other nozzles, they have a higher potential for spray drift.
- **Solid cone nozzles:** Herbicide spot spraying is accomplished with solid cone nozzles, which generate a solid cone spray pattern. It is similar to hollow-cone nozzle in design with the addition of an internal jet, which strikes the rotating liquid just within the orifice of discharge. The primary cause of spray droplet breaking is impact action. It is advised to apply herbicides to the soil using full-cone nozzles.
- **Flood nozzle:** Flood nozzle makes a wide-angle flat spray pattern. Compared to other nozzles, it operates at lower pressure. Across its width, the spray pattern is rather consistent. These are sprayed with fertiliser solutions and systemic herbicides. In general, these nozzles are not appropriate for applying contact herbicides.

- **Triple-action nozzles:** Triple-action nozzles are more popular because this can produce three types of spray pattern by adjustment like a jet, a solid-cone and a hollow cone. They work well with tractor-drawn sprayers and can be used for both large and low volume spray applications. The components of the triple-action nozzle are the nozzle disc, swirl plate, swirl chamber, and cap. Pressure significantly affects how well a nozzle performs. Wider spray angles, finer droplets, and increased discharge are the results of increased pressure.
- **Rotary nozzle:** For aerial applications, rotary nozzle or controlled droplet atomizer have been employed. Aero-blast sprayers were also used with these nozzles. The rotary nozzle atomizes the spray by using a rotating spinner and centrifugal force rather than forcing the liquid through a hydraulic orifice. Rotary nozzles are of two types: (i) spinning disc and (ii) spinning cage or screen basket. The droplet size depends on speed of the spinning disc. The droplet size decreases with increasing speed.

Factors that affect spray pattern

Nozzle size and pressure are two important factors that affect the spray pattern of a sprayer. The size of the nozzle determines the droplet size and coverage. Smaller droplets provide better coverage, but larger droplets are less likely to drift (Griesang et al., 2022). The pressure of the sprayer also plays a role in the spray pattern. Increasing the pressure can improve the distribution and uniformity of the spray, but there is a limit to the effectiveness. Too high of a pressure can result in decreased quality of distribution (Sies et al., 2019). The relationship between droplet size and pressure can be fitted as a power function, with smaller variations in droplet size as pressure increases (Grisso, 2019). Therefore, choosing the right combination of nozzle size and pressure is crucial for achieving the desired spray pattern and optimizing the performance of the sprayer.

Wind speed, direction, target crop and boom height are all factors that can affect the spray pattern of a sprayer. The wind speed can have a significant effect on spray drift, with higher wind speeds resulting in increased drift (Kavitha et al., 2023). The target crop also plays a role, as different crops may have different canopy structures that can affect spray penetration and deposition. Additionally, the boom height of the sprayer can impact the spray distribution. Studies have shown that boom height variations can occur, with the sides of the boom experiencing the greatest variation (Kavitha et al., 2023). It has also been observed that the height of the drone sprayer can influence the spray volume distribution, with direct impacts from downwash airflow affecting the spray pattern (Hipkins et al., 2009). Therefore, it is important to consider wind speed and direction, the characteristics of the target crop, and the boom height when optimizing spray patterns for effective and efficient pesticide application.

How a spray pattern can be optimized

Spray patterns can be optimized by controlling the physical properties of the spray and using real-time feedback control (Bothell et al., 2020). The optimization process involves adjusting parameters such as the spray angle, droplet size spectrum, and coverage (Купреенко et al., 2023). Computer modeling and simulation methods can be used to determine the optimal design parameters for sprayers under different operating conditions (Pütz, 2019). Understanding the physics of spray systems, including atomization and the behavior of the particulate phase, is crucial for developing accurate computational models (Hewitt, 2008). Experimental data and empirical models can also be used to predict and optimize spray characteristics, such as droplet size and drift (JY Pun - US Patent App. 12/589 & 2011, n.d.). By modifying the structure and components of sprayers, spray patterns can be controlled and optimized to achieve a desired spray target profile.

Benefits of optimizing spray pattern

Optimizing spray patterns offers several benefits. It helps to improve fuel efficiency and reduce emissions in internal combustion engines. It allows for the effective control of pests in agroecosystems, minimizing the number of parasites and their impact on the ecosystem (Silva et al., 2017). Additionally, optimizing spray patterns in thermal spray coatings helps to enhance the properties of the coatings by identifying and minimizing flaws caused by inadequate processing (Sexsmith & Troczynski, 1994). Furthermore, analyzing spray distribution nozzles and considering factors such as water consumption and spray angle can lead to more accurate and efficient applications in various fields, including combustion processes and agriculture (Dombrowski & Hooper, 1962).

Conclusion

Spray pattern optimization is crucial for effective plant protection. It helps to improve the efficacy of crop protection products, reduce the risk of drift, and improve crop health and yield. By following the best practices for spray pattern optimization, growers can achieve their production goals while minimizing the environmental impact of crop protection products.

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