Environmental Constraints on Spring Suppression in Perennial Groundcover Systems

A 25-year Analysis of Sprayable Hours for Glufosinate, Saflufenacil, and Paraquat Across the U.S. Corn Belt

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This fact sheet was developed as part of research conducted under the RegenPGC project, supported by Agriculture and Food Research Initiative Competitive Grant no. 2021-68012-35923 from the USDA National Institute of Food and Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this presentation are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Context

Perennial Groundcover (PGC) systems maintain a living perennial vegetation layer beneath annual cash crops such as corn and soybeans. These systems have the potential to improve soil conservation, reduce erosion, enhance water infiltration, increase soil cover, and provide other environmental benefits associated with maintaining living roots and year-round ground cover.

A key management challenge in PGC systems is balancing the benefits of the perennial groundcover with the need to produce a productive corn or soybean cash crop. Consequently, early-season suppression is often necessary to reduce competition between groundcover and emerging crops. Previous studies in living mulch and perennial groundcover systems have reported reduced maize performance and grain yield when actively growing groundcover vegetation was inadequately suppressed during early crop development (Martin et al., 1999; Zemenchik et al., 2000; Wiggans et al., 2012). These yield reductions have been associated with early-season competition and shade avoidance responses triggered by actively growing groundcover species (Bartel et al., 2022). In the absence of adequate suppression, groundcovers can compete for light, water, and nutrients, potentially reducing crop establishment, early-season growth, and yield.

Successful herbicide applications are influenced by multiple environmental conditions, including wind speed, temperature, relative humidity, cloud coverage, and the presence of rain-free periods following application. These environmental factors can substantially affect both operational spray opportunities and herbicide performance in the field.

This fact sheet evaluates environmental constraints on herbicide application during the planting window (April 1–June 1) across the U.S. Corn Belt using 25 years of hourly weather data. The analysis focuses on regional variability in “sprayable hours” and on the dominant environmental factors limiting application, providing insight into operational challenges associated with different suppression strategies.

To illustrate how environmental requirements influence potential application windows, three herbicides commonly used in corn and soybean systems were evaluated: glufosinate, saflufenacil, and paraquat. These herbicides differ substantially in environmental requirements, operational flexibility, crop safety considerations, and stewardship concerns.

The sprayable-hour estimates presented here were generated using conservative application thresholds derived from product labels and peer-reviewed literature and are intended to represent idealized application conditions. However, field observations from PGC systems suggest that successful suppression may still occur outside these idealized thresholds under certain field conditions w hen applications are properly managed.

Study Design

Timeframe: Hourly data from April 1 – June 1 from 2001 to 2025 (~37,000 hours) from public database (NASA POWER Project)

Spatial coverage: 919 counties across 10 states (Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin), with 5 random sampling points per county (~4,600 total sampling locations)

Dataset size: ~170 million hourly observations

Thresholds for Sprayable Conditions

Environmental thresholds were based on herbicide label information and published literature and define acceptable field conditions for spraying, including wind speed, temperature, relative humidity, rainfastness, and cloud coverage (Table 1). Responses to these factors differ by active ingredient and target species. For instance, glufosinate efficacy declines under cooler temperatures and is strongly affected by environmental interactions (Kumaratilake and Preston, 2005; Takano and Dayan, 2021). Saflufenacil performance is likewise influenced by temperature, growth stage, and seasonal conditions (Dennis et al., 2016). Paraquat, a contact herbicide, is primarily affected by temperature and light, with efficacy generally enhanced under warm conditions when plants are actively growing (Harre et al., 2021). Unlike the other herbicides evaluated, paraquat has lower sensitivity to relative humidity, rainfastness, or cloud coverage within application threshold contexts, resulting in fewer environmental constraints on spray timing.

Table 1. Environmental thresholds used to define sprayable conditions for glufosinate, saflufenacil, and paraquat during the planting window (April 1–June 1), based on label guidance and literature.

Active ingredient	Wind Speed	Temperature	Relative Humidity	Rainfastness	Cloud Coverage
Glufosinate	<10 mph	>60°F	>50%	4 hours	<50%
Saflufenacil	<10 mph	>50°F	>50%	1 hour	<60%
Paraquat	<10 mph	>55°F*	No minimum	No rain at time of application	No limit

*Cool temperatures may reduce activity, but do not necessarily prevent efficacy.

Hours were classified as sprayable if they met the above-mentioned requirements within working hours (9 AM–5 PM local time), representing a conservative, performance-focused application window. Extending the working period beyond these hours would likely increase the total number of sprayable hours.

Key Findings

The following maps show the spatial distribution of average annual sprayable hours during the planting window (April 1–June 1) for glufosinate, saflufenacil, and paraquat.

Across all three herbicides, a clear spatial gradient is observed. Higher sprayable hours are consistently concentrated in southern and eastern regions, particularly in southern Missouri, southern Illinois, Indiana, and Ohio. In contrast, northern and western areas, including South Dakota, Nebraska, and western Kansas, show lower values. This pattern reflects more favorable early-season conditions in the south and east compared to cooler or drier conditions in the north and west.

The magnitude of sprayable hours varies substantially among herbicides, highlighting the strong influence of application thresholds on operational feasibility under the environmental assumptions used in this analysis.

Glufosinate (Figure 1) shows the most restrictive pattern (0–80 hours). Large portions of the western regions fall within the lowest classes (0–5 hours), with most of the central regions also falling within 5–20 hours. Even in more favorable regions (southern and eastern), values are generally constrained to moderate ranges (20–80 hours), representing around 25% of the study area. This reflects the combined effect of stricter environmental requirements, which reduces the number of suitable application windows under idealized application conditions.

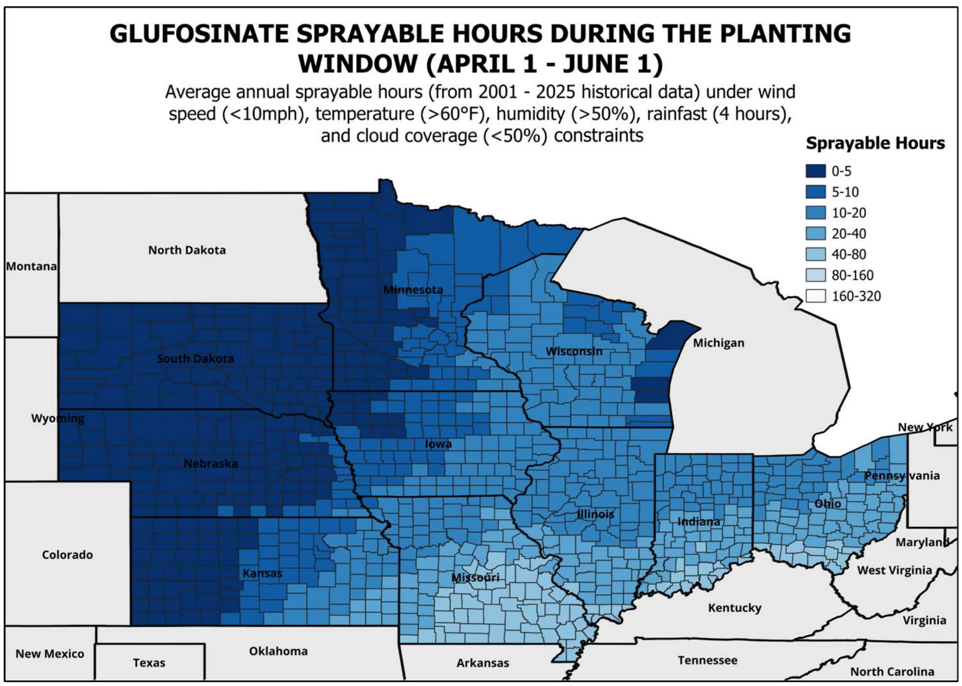

Figure 1. Average annual sprayable hours during the planting window (April 1–June 1) for **glufosinate**, based on 25 years (2001–2025) of hourly weather data and application thresholds for wind speed, temperature, relative humidity, rainfall/rainfastness, and cloud coverage.

However, field observations from PGC systems suggest that successful suppression may still occur outside these idealized thresholds when applications are properly managed. For example, observations from Kansas and Nebraska demonstrated strong suppression following glufosinate and saflufenacil applications under relatively low humidity conditions. In the Kansas glufosinate example, applications were made using a 20 GPA carrier volume and ammonium sulfate (AMS).

Saflufenacil (Figure 2) exhibits an intermediate pattern (0–160 hours). Large portions of the western regions fall within lower classes (0–10 hours), with much of the central Midwest ranging between 10–40 hours. In more favorable regions (southern and eastern), values extend into higher classes (40–80 hours), with some areas reaching 80–160 hours. This reflects the relaxation of temperature thresholds, shorter rainfastness requirements, and greater tolerance to cloud coverage, which increases the number of suitable application windows.

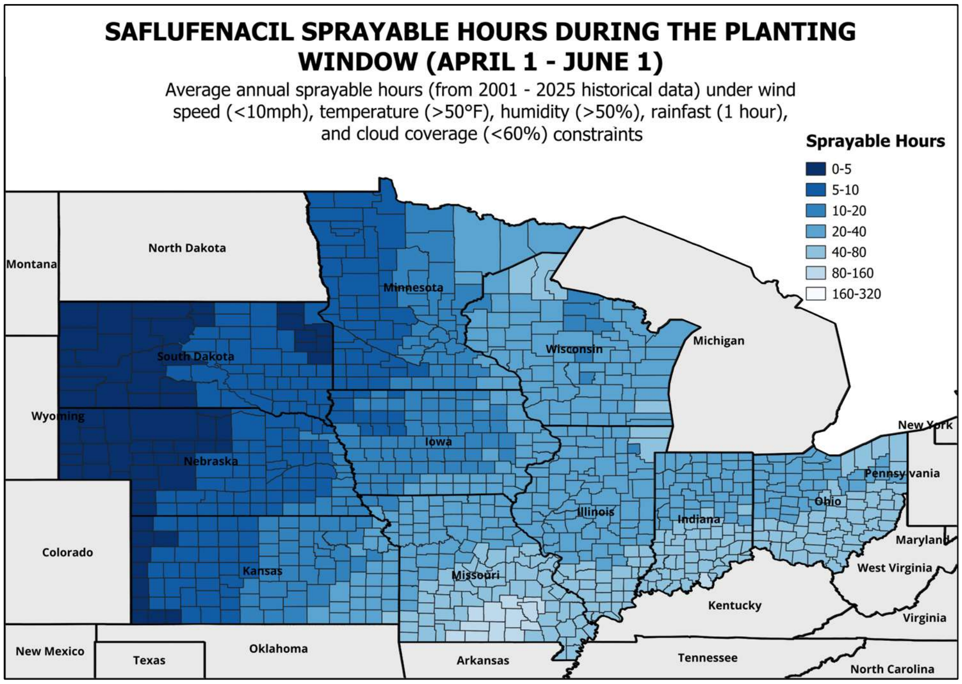

Figure 2. Average annual sprayable hours during the planting window (April 1–June 1) for **saflufenacil**, based on 25 years (2001–2025) of hourly weather data and application thresholds for wind speed, temperature, relative humidity, rainfall/rainfastness, and cloud coverage.

Paraquat (Figure 3) shows the least restrictive pattern (10–320 hours). The lowest values are concentrated in the northwestern portion of the study area, where some counties fall within the 10–20 hours class. Higher values are observed across much of the central and eastern Corn Belt, with most of Kansas, northern Missouri, southern Wisconsin, western Ohio, and large portions of Iowa, Illinois, and Indiana falling within the 80–160 hours class. The highest values occur in southern and eastern areas, particularly southern Missouri, southern, Indiana, and eastern Ohio, where some counties reach 160–320 hours.

Overall, the maps show that regional weather patterns define baseline spatial variability, while herbicide-specific requirements strongly influence potential spray hours and operational constraints. The results should be interpreted as indicators of relative operational feasibility under conservative application assumptions rather than absolute predictors of field success or herbicide performance.

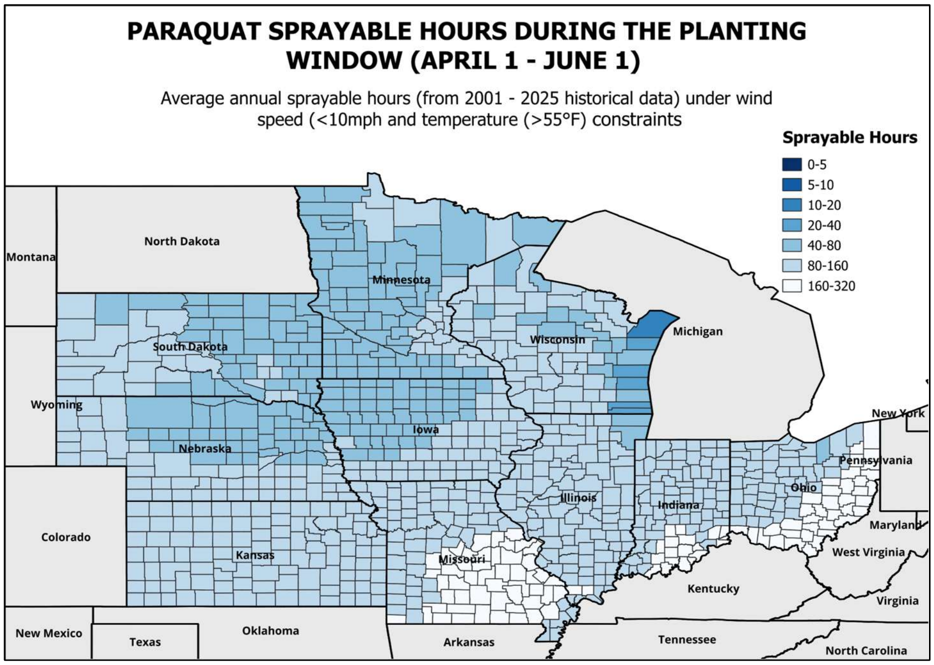

Figure 3. Average annual sprayable hours during the planting window (April 1–June 1) for **paraquat**, based on 25 years (2001–2025) of hourly weather data and application thresholds for wind speed and temperature.

The following maps show the dominant environmental factor limiting herbicide application during the planting window.

Across all herbicides, clear regional clustering is observed, indicating that environmental constraints on application are not uniformly distributed but instead driven by distinct climatic patterns across the Corn Belt. However, the dominant limiting factor varies substantially depending on the herbicide, reflecting differences in application requirements. For glufosinate (Figure 4), multiple limiting factors are observed across the region. Wind speed is the dominant constraint across much of the central Midwest. Low temperature is the primary limitation in northern areas such as northern Minnesota and Wisconsin, where cooler spring conditions delay suitable application windows. In western regions, including Nebraska, South Dakota, and western Kansas, low relative humidity is the most frequent limiting factor, reflecting drier atmospheric conditions. Cloud coverage becomes a dominant constraint in southern and eastern areas, particularly across Missouri, southern Illinois, Indiana, and Ohio.

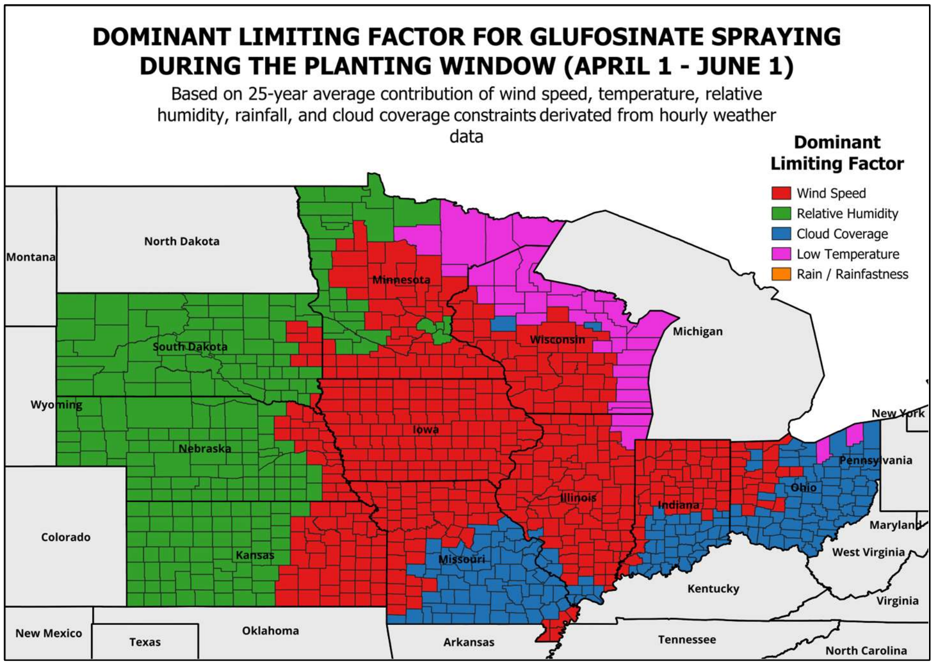

Figure 4. Dominant limiting factor for herbicide application during the planting window (April 1–June 1) for **glufosinate**, based on the most frequent environmental constraint (wind speed, temperature, relative humidity, rainfall/rainfastness, or cloud coverage) preventing an hour from being classified as "sprayable".

Saflufenacil (Figure 5) exhibits a pattern similar to glufosinate, although wind speed becomes the dominant limiting factor across a larger portion of the study area. Across most of the central and eastern Corn Belt, wind is the primary limiting factor, indicating that fewer environmental constraints restrict application under its less stringent thresholds. Low relative humidity remains the dominant limitation in western regions, particularly in Nebraska and western Kansas. Low temperature persists as a limiting factor in northern areas, although its spatial extent is reduced compared to glufosinate. Cloud coverage remains a dominant constraint in southern and eastern areas, now including some northern counties across Minnesota and Wisconsin.

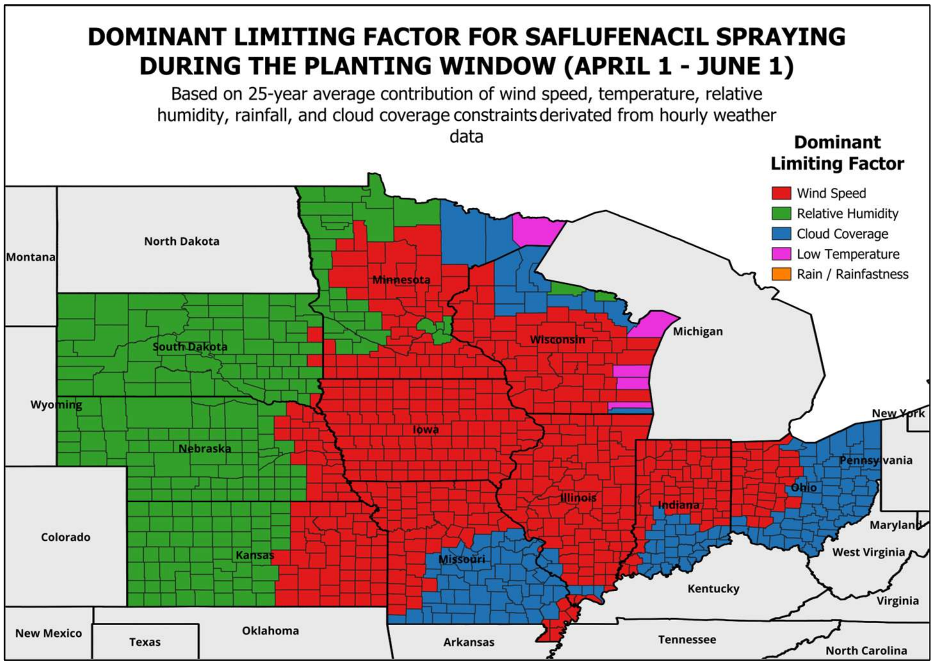

Figure 5. Dominant limiting factor for herbicide application during the planting window (April 1–June 1) for **saflufenacil**, based on the most frequent environmental constraint (wind speed, temperature, relative humidity, rainfall/rainfastness, or cloud coverage) preventing an hour from being classified as "sprayable".

Paraquat (Figure 6) exhibits a highly simplified pattern, with wind speed overwhelmingly showing as the dominant limiting factor across nearly the entire study area. This reflects the fewer environmental restrictions associated with its application requirements, where only wind speed and temperature thresholds are considered. Low temperatures remain a limiting factor in northern regions such as Minnesota and Wisconsin, while rainfall appears as localized constraint in southern areas.

Overall, these results demonstrate that as herbicide application requirements become less restrictive, the number of dominant limiting factors decreases and constraints become more concentrated around a smaller set of environmental variables. While multiple interacting factors limit applications for more restrictive herbicides such as glufosinate, fewer constraints, like wind speed, govern application opportunities for less restrictive herbicides such as paraquat. This highlights how herbicide selection influences not only the number of available spray hours but also the primary sources of operational limitation across regions.

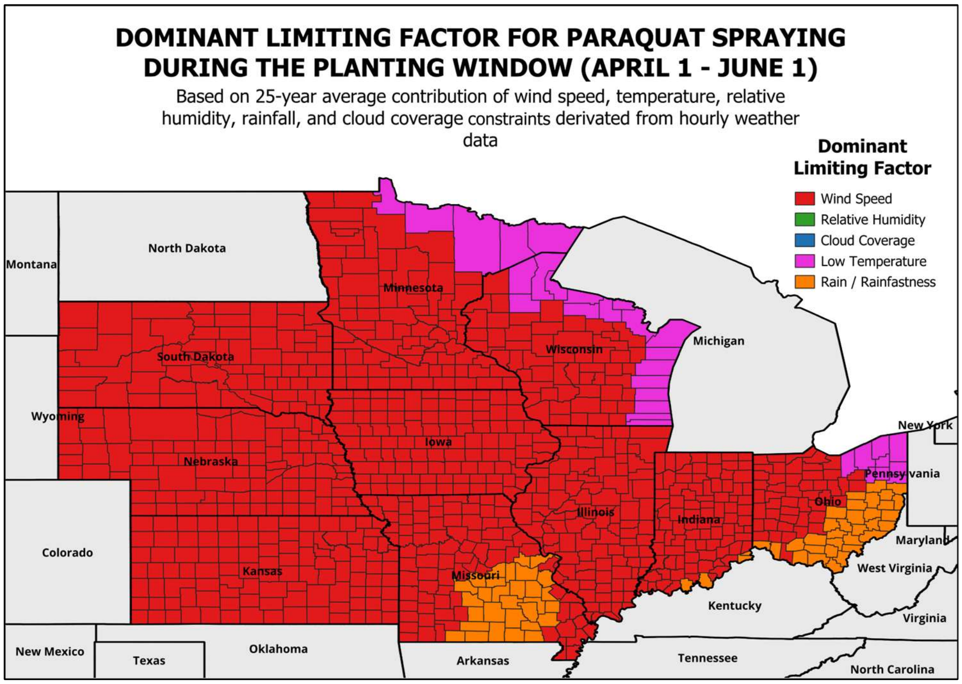

Figure 6. Dominant limiting factor for herbicide application during the planting window (April 1–June 1) for **paraquat**, based on the most frequent environmental constraint (wind speed, temperature, or rainfall/rainfastness) preventing an hour from being classified as “sprayable”.

Field Observations and Practical Considerations

Field observations from PGC systems suggest that successful suppression may still occur outside the conservative environmental thresholds used in this analysis. Figure 7 shows Kentucky bluegrass suppression near Salina, Kansas following a glufosinate application made under approximately 72°F and 30% relative humidity conditions. Although relative humidity was below the 50% threshold used to define sprayable hours in this study, substantial suppression was observed. In this case, the application was made using a 20 GPA carrier volume and ammonium sulfate (AMS), illustrating how management practices may influence field performance.

Figure 7. Kentucky bluegrass suppression following glufosinate application near Salina, Kansas.

Similarly, Figure 8 shows suppression of *Poa bulbosa* near Salina, Kansas following glufosinate application under the same environmental conditions.

Figure 8. Poa bulbosa suppression following glufosinate application near Salina, Kansas.

Figure 9 shows suppression of *Poa bulbosa* near York, Nebraska following a saflufenacil application under approximately 78°F and 19% relative humidity conditions. Although relative humidity conditions were well below the threshold used in this study, substantial suppression was observed, demonstrating that field outcomes may not always align with idealized application criteria.

Figure 9. Poa bulbosa suppression following saflufenacil application near York, Nebraska.

In PGC systems, suppression timing is constrained not only by crop development stage but also by herbicide use restrictions. Because saflufenacil and paraquat are generally limited to pre-plant or pre-emergence applications, growers have a relatively narrow window to achieve suppression before crop establishment. In years with limited favorable weather conditions, ideal application thresholds may not always be met during this critical spring suppression period.

In some situations, growers may choose to accept greater application risk to achieve suppression during critical early-season periods. This is particularly relevant in PGC systems where insufficient suppression can increase competition with the cash crop and potentially reduce yield. In contrast to paraquat and saflufenacil, glufosinate also provides additional operational flexibility because it can be applied after crop emergence as a rescue treatment when pre-emergence suppression opportunities are limited.

Consequently, the maps presented here should be interpreted as tools for understanding relative operational feasibility and environmental risk rather than strict boundaries between successful and unsuccessful applications.

Conclusion

Environmental conditions during the planting window impose clear and region-specific constraints on herbicide application across the U.S. Corn Belt. Sprayable hours are consistently lower in northern and western areas and higher in southern and eastern regions, reflecting underlying temperature, relative humidity, and weather patterns.

Herbicide-specific requirements strongly influence both the number of available spray hours and the factors that limit application. More restrictive herbicides, such as glufosinate, result in fewer sprayable hours and are limited by multiple interacting environmental conditions, including low temperature, relative humidity, wind speed, and cloud coverage. In contrast, less restrictive herbicides, such as paraquat, provide greater operational flexibility within the environmental assumptions used in this analysis, with wind emerging as the primary limiting factor across most regions.

These findings highlight that application timing is shaped not only by weather variability but also by herbicide selection. Understanding regional constraints and dominant limiting factors can support more effective planning and reduce the risk of missed spray windows during critical early-season operations.

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