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Weed Population Impacts Using Targeted Herbicide Applications with See & Spray™ in Soybean over a Three-year Period

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Abstract

Targeted herbicide applications have the potential to reduce herbicide inputs but pose an inherent risk of missing weeds resulting in late-season escapes. Furthermore, relying on targeted residual herbicides may increase weed emergence relative to broadcast applications. Research was conducted over a three-year period in Keiser, AR, to compare traditional broadcast applications to targeted postemergence applications in glyphosate-, glufosinate-, and dicamba-resistant soybean. The herbicide program was consistent across treatments with a broadcast-applied preemergence residual, and a postemergence program including glufosinate + glyphosate + *S*-metolachlor followed by glufosinate + acetochlor, both broadcast- or target applied at the highest and lowest spray sensitivities. The soil seedbank was similar at trial initiation across treatments, and there was no increase over three years for broadcast and targeted applications at the highest sensitivity. Averaged over application timing, the lowest sensitivity increased the weed density from 867 plants ha^{-1} to 2,870 plants ha^{-1} in year two, to 11,300 plants ha^{-1} in year three. This response is likely due to more Palmer amaranth escapes at harvest (averaged over years) with >1,000 plants ha^{-1} compared to the highest sensitivity and broadcast treatments. Targeted applications did improve profitability by reducing herbicide use and increasing application efficiency, providing averaged savings of USD \$43.22 ha^{-1} to \$129.19 ha^{-1} relative to broadcast postemergence cost of \$227.22 ha^{-1}. Area sprayed was reduced by 20% to 90%, with the average at early-postemergence being 41.3% and 57.9% and at mid-postemergence equaling 48.1% and 49.3% for the lowest and highest sensitivities, respectively. The only difference in the area sprayed between sensitivity settings occurred early postemergence. Based on the results of this experiment, producers could utilize targeted applications postemergence in soybean to increase profitability, but the lowest sensitivity resulted in unacceptable increases to the weed seedbank, which could impact management in future years.

Nomenclature: Palmer amaranth, *Amaranthus palmeri* S. Watson; soybean, *Glycine max* (L.) Merr.

Keywords: Spot-spray, site-specific-management, soil seedbank, precision sprayer, John Deere

Introduction

Crop production across the United States faces increasing pressure to reduce pesticide inputs to mitigate environmental loading and reduce off-target movement (Anonymous 2024). Additionally, rising input costs put more pressure on producers to maintain profitability (USDA-NASS 2025). Weeds are often not uniformly distributed across a field and typically emerge in clumps or patches (Cardina et al. 1997; El Jgham et al. 2023; Franz et al. 1991; Metcalfe et al. 2019; Rew and Cousens 2001; Sapkota et al. 2020; Stafford and Miller 1993; Wiles et al. 1992). Site-specific management of weeds offers an opportunity to reduce herbicide inputs. Real-time targeted herbicide applications provide a way to reduce environmental loading, potentially improve profitability, and efficiently control weeds without drastic changes to production practices (Avent et al. 2024; El Jgham et al. 2023; Gianessi and Reigner 2007; Stafford and Miller 1993; Wiles et al. 1992).

In 2022, John Deere released the See & Spray™ (Deere & Company, Moline, IL) Ultimate technology, which features a dual-boom sprayer capable of simultaneous broadcast and targeted pesticide applications (Anonymous 2025; Gizotti de Moraes 2024; Lazaro et al. 2024). In the following year, the company introduced a single-tank platform, which can be purchased new or retrofitted to some existing sprayers. Both systems utilize machine vision and deep learning to detect weeds in fallow systems or distinguish weeds from certain row crops, allowing real-time applications to weeds (Fu et al. 2022; Padwick et al. 2023; Redden 2023). Previous research in soybean and corn (*Zea mays* L.) comparing targeted applications to broadcast applications demonstrated comparable weed control with a program approach (Avent et al. 2024; Leise et al. 2025). In Nebraska, Leise et al. (2025) reported corn herbicide programs with targeted applications providing ≥ 90% Palmer amaranth control with Greeneye Technology™ (Greeneye Technology, Tel Aviv-Yafo, Israel). In the soybean experiment, targeted applications with See & Spray provided higher waterhemp [*Amaranthus tuberculatus* (Moq.) J.D. Sauer] control than broadcast applications (92% vs 91%; Leise et al. 2025). Avent et al. (2024) reported no biological Palmer amaranth control differences between targeted and broadcast applications, both providing ≥ 94% control after early-postemergence applications. Both publications utilized specific machine settings and emphasized how altering settings could impact results. However, Leise et al. (2025) utilized settings at the highest detection level, and Avent et al. (2024) used a medium detection setting.

Previous research from 2022 across 11 independent experiments in corn, cotton (*Gossypium hirsutum* L.), and soybean evaluated how changes in the sensitivity setting influenced the likelihood of treating weeds with postemergence applications (Avent et al. 2025). Changing from a broadcast application to the lowest sensitivity reduced the likelihood of treating *Amaranthaceae* weeds between soybean rows from >99% to approximately 55% when the weeds were 1.9 cm tall and 2.5 cm wide. The substantial reduction in the ability to treat these weeds is concerning due to the widespread herbicide resistance in Palmer amaranth and waterhemp (Carvalho-Moore et al. 2025; Evans et al. 2019; Foster and Steckel 2022; Heap 2024; Randell-Singleton et al. 2024). Combined with the fact that both species are prolific seed producers, missing weeds at susceptible growth stages is unacceptable from a herbicide resistance management perspective (Bagavathiannan and Norsworthy 2012; Heneghan and Johnson 2017; Norsworthy et al. 2012; Spaunhorst et al. 2018).

Another limitation of targeted applications is the potential for reduced residual herbicide use. Since operators usually prioritizes higher efficiency by reducing spray volumes and spraying at high speeds (Butts et al. 2021; Mississippi State University, Department of Agricultural Economics 2025), applicators may be inclined to target-apply residuals using single-tank systems. To mitigate herbicide resistance evolution, weed scientists across the United States advocate for overlapping residual herbicides (Barker et al. 2023; Boyd et al. 2022; Chahal et al. 2018; de Sanctis et al. 2021). Additionally, research on new commercial spray technologies that perform simultaneous detection and application is limited, particularly when considering the ecological impact on the weed seedbank from continuous use of these technologies or at different detection settings. Therefore, research was initiated to address the potential impacts of utilizing targeted herbicides (postemergence- and residual-active) at the highest and lowest detection settings compared to traditional broadcast applications in soybean.

Materials & Methods

Site, Design, and Field Data Collection

A three-year soybean experiment was initiated at the Northeast Research and Extension Center (NEREC) in Keiser, AR (35.674281, -90.077891), on May 3, 2022. Plots were marked and kept consistent yearly to monitor the weed seedbank changes by marking the four corners of the trial immediately after harvest. Plot dimensions were eight rows (7.7 m) wide by 67 m in length, with 96.5 cm between each soybean row. In 2022, AG45XF0 soybean were planted at 350,000 seed ha^{-1}, and due to lodging, B4885XF soybean were planted in the following years at the same seeding rate. Lodging across the field was <15% and not dependent upon treatment. The experimental site was mainly a Steele loamy sand (sandy over clayey, mixed, superactive, nonacid, thermic Aquic Udifluvent) consisting of 64% sand, 16% silt, 20% clay, 6.8 pH, and 2.1% organic matter (Soil Testing and Research Laboratory, Marianna, AR). The production system utilized was conventional tillage with raised beds hipped in the fall before shaping the beds in the spring. Other cultural practices included no pre-plant soil amendments due to historical soil test values, and furrow irrigation was performed to supplement rainfall each week to provide 2.5 cm total throughout the week. Soybean planting occurred on May 4, 2022, May 18, 2023, and April 23, 2024.

In-season production practices are listed in Table 1. Early-postemergence applications occurred 19 to 39 days after planting, with mid-postemergence applications occurring 11 to 21 days after the early-postemergence application. The reason for different application intervals from year to year was to simulate a program approach in which applications were triggered when newly emerged Palmer amaranth was present and approximately 7.5 cm. Additionally, rainfall and irrigation events partly impacted when applications occurred each year. If no new weeds were present at the mid-postemergence application, the application occurred as soon as the soybean reached the R1 growth stage.

The experiment was organized as a randomized complete block design (RCBD) with three treatments and six replications. Each treatment received a broadcast application at planting, consisting of the same herbicide program (Table 2), but differed by application method postemergence. The different application methods were a broadcast standard, targeted

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applications at the lowest See & Spray sensitivity, and targeted applications at the highest sensitivity. All herbicide applications occurred with a scaled dual-boom See & Spray small-plot machine previously described by Avent et al. 2024. The sprayer was mounted to the front-end loader of a tractor and equipped with 10 nozzles spaced 38.1 cm apart. The sprayer was calibrated to deliver 140 L ha^{-1} at 283 kPa while traveling 19.3 kph with rearwardly inclined PS3DQ0005 nozzles (medium droplet classification; Deere & Company, Moline, IL). The small spray buffer setting was used for postemergence applications. The detection models used throughout the years were subject to change due to system updates, and each year, the detection algorithms matched what was available to commercial sprayers.

In-season data included weed density assessments at postemergence application timings of all species. Postemergence applications included blue dye (Super Signal Blue, Precision Labs LLC, Kenosha, WI, USA) at 0.25% (v/v) to indicate whether weeds were missed after application. At application weed counts and misses were determined for the length of each plot between soybean rows two and three and rows six and seven, equating to 129.3 m^2 plot^{-1}. Weeds missed were divided by the weeds present at application, and total weed counts per 129.3 m^2 were extrapolated to hectares. Palmer amaranth was the most abundant weed, but other species included prickly sida (*Sida spinosa* L.), morningglory (*Ipomoea* spp.), horse purslane (*Tranthema portulacastrum* L.), and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster].

At harvest, reproductive Palmer amaranth escapes were counted for the entire plot. All plots were harvested with a John Deere S690 (Deere & Company, Moline, IL), and grain samples were collected for each plot to calculate moisture and adjusted to 13%. Plot-to-plot contamination from wind-blown chaff exiting the combine was not prevented, but to prevent additional contamination of settled chaff, beds were reshaped within three days after harvest and marked to keep plots consistent from one year to the next. Additional data included area sprayed metrics recorded by the small-plot sprayer.

Exhaustive Germination Data Collection

At planting in 2022 and after harvest in 2024, twenty soil samples were collected from each plot to estimate the weed seedbank at trial initiation and termination. Each sample was collected with an 11.4 cm diameter cup-cutter to a 7.5-cm depth. A total of 20 samples were composited plot^{-1}. After soil collection, samples were homogenized, total mass recorded, and a 2 kg subsample was placed in a 52 x 40 x 5 cm plastic greenhouse tray filled with a 1:1 ratio (V:V) of potting soil (PRO-MIX BX, Greenhouse Megastore, Danville, IL) to field soil. Exhaustive germination was conducted in a greenhouse located in Fayetteville, AR, with approximate nighttime temperatures at 21.1 C and daytime temperatures at 30 C with a 16 hr photoperiod. Each tray was watered over-the-top twice daily and no fertilizer amendments were applied. Emerged weeds by tray were counted and pulled for four weeks. Thereafter, trays were placed in a subzero freezer for two weeks. This cycle repeated for four times. Weeds tray^{-1} were extrapolated to m^2 by accounting for the cup-cutter cross-sectional area, soil mass collected plot^{-1}, and the 2 kg subsample. Palmer amaranth ending counts were subtracted from the beginning counts to calculate Δ Palmer amaranth m^2.

Economics Data Collection

To determine the economics of the different treatments, 10-year average costs were determined for all herbicides, interest rates, and labor from the Mississippi State Archived Budgets and adjusted for inflation over the previous five years (Mississippi State University, Department of Agricultural Economics 2025). The interest and labor rates were then incorporated into the University of Arkansas System Division of Agriculture Enterprise Budgets to calculate fixed and variable costs, assuming a $600,000 broadcast sprayer and the two extremes for a See & Spray Premium upgrade, $40,000 and $80,000 (Watkins 2024; https://configure.deere.com/). The two See & Spray Premium sprayer costs were added to the budget at $640,000 and $680,000. The $40,000 difference between a broadcast and See & Spray Premium assumes two comparable sprayers already equipped with the required GPS and nozzle bodies and only requires camera, vision processing units, and wiring harness installation. The $80,000 upgrade assumes a base-model sprayer needing all upgrades to facilitate targeted applications. The economic analysis compared differences within each application timing and total costs.

Each scenario incorporated the application, subscription, and herbicide costs on a hectare basis. Subscription costs are reported at $12.36 ha^{-1} on the area not sprayed. For instance, if 40%

of a hectare was sprayed, the cost is \$7.41. On average, broadcast sprayers in Arkansas travel approximately 24.2 kph (Butts et al. 2021), whereas See & Spray Premium is restricted to 19.3 kph. The different speeds impacted fuel and labor costs, while the fixed and repair costs differed due to machine valuation. The Fixed, repair, fuel, and labor costs for a broadcast sprayer were \$14.97, \$1.19, \$0.82, and \$0.32 ha^{-1}, respectively. Fixed, repair, fuel, and labor costs for targeted applications were \$19.49, \$1.55, \$1.01, and \$0.40 ha^{-1} for the \$40,000 upgrade and \$21.21, \$1.68, \$1.01, and \$0.40 ha^{-1} for the \$80,000 upgrade.

Data Analysis

All data were analyzed using JMP Pro Version 18 (SAS Institute, Carey, NC). Yearly data were analyzed as a repeated measure with an unstructured covariance considering application method, application timing (only for counts and misses), and year as fixed effects. Changes in Palmer amaranth density from exhaustive germination were analyzed as a one-way analysis. Blocks were considered random effects. The collective density of all weeds at both postemergence applications and the density of Palmer amaranth escapes at the end of the season were analyzed using generalized linear mixed models with a Poisson distribution. Weed misses were analyzed with a normal distribution due to skewed residuals with Poisson, gamma, lognormal, negative binomial, and exponential distributions. Yield, area sprayed, and application costs passed equal variance and residual assumptions and were analyzed as standard least squares. Yield and total postemergence application costs were analyzed using only the year as a repeated measure.

All data subjected to ANOVA were considered significant at $P \leq 0.05$, and the means were separated using Tukey's HSD ($\alpha = 0.05$). All data figures are displayed with box and whisker plots of the observed data, and compact letters displayed on graphs are based on the least square means. Additionally, a planned orthogonal contrast was utilized to address whether targeted residual applications at early postemergence increased the number of weeds present at mid-postemergence relative to the broadcast treatments. Another important consideration was the presence of potential outliers in the dataset. Since all collected data were continuous, outliers were not excluded from the analysis.

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Results & Discussion

For the weed densities, a significant interaction between application method by year and application timing by year occurred (Table 3). In 2022, all treatments exhibited similar weed densities within each application timing, which averaged 1,500 and 270 plants ha^{-1} at early- and mid-postemergence, respectively (Figure 1). The similarities at trial initiation are important to consider since differences indicate the need to either consider the initial population as a covariate in the analysis or calculate the change in population density. The weed density following broadcast and targeted applications at the highest sensitivity showed no increase throughout years. However, targeted applications at the lowest sensitivity increased yearly, with the greatest overall density in 2024. Similarly, the soil seedbank estimates indicated that after three soybean production seasons, Palmer amaranth germination increased by 783, 1077, and 2,246 plants m^{-2} for broadcast, targeted applications at the highest sensitivity, and targeted applications at the lowest sensitivity, respectively (Table 4). The increased counts can be explained by the main effect of application method on Palmer amaranth escapes present at harvest (Table 5). Averaged over the years, targeted applications at the lowest sensitivity caused the greatest number of Palmer amaranth escapes at 1,380 Palmer amaranth escapes ha^{-1} compared to 268 and 343 escapes ha^{-1} for broadcast and the highest sensitivity, respectively (Table 5 & Figure 2).

While not statistically significant, the weed density at application increased by 67% for broadcast and targeted applications at the highest sensitivity each year, while programs utilizing the lowest sensitivity experienced a significant average 262% weed density increase each year (Figure 1). With the numerical increase in weed density and Palmer amaranth seedbank for plots treated with broadcast and targeted applications at the highest sensitivity, some plot-to-plot contamination cannot be ruled out. Palmer amaranth has demonstrated the ability to laterally move more than 5 m from one year to the next (Norsworthy et al. 2014), meaning plants at the edge of plots could easily disperse seed to adjacent plots. The increasing weed density is concerning from a herbicide resistance management perspective (Norsworthy et al. 2012), especially with the current herbicide-resistant Palmer amaranth cases spreading across the United States (Brabham et al. 2019; Carvalho-Moore et al. 2022; Foster and Steckel 2022; Heap 2024; Hwang et al. 2023; Randell-Singleton et al. 2024). In Arkansas, for example, a Palmer amaranth population was recently reported resistant to seven postemergence herbicide sites of action (Carvalho-Moore et al. 2025).

Based on the weed density results, targeted applications at the lowest sensitivity are increasing selection for herbicide resistance genes through the yearly increase in weed density (Jasieniuk et al. 1996), especially due to misses at early-postemergence at the lowest sensitivity, which led to higher plant densities at the mid-postemergence application (Figures 3 and 4). Additionally, targeted applications of *S*-metolachlor early-postemergence with the lowest sensitivity increased the weed density present at mid-postemergence compared to the other application methods (Table 6). Averaged over the years and after subtracting the weeds missed at early-postemergence, the weed density present at mid-postemergence averaged 840, 989, and 4310 plants ha^{-1} for broadcast applications, targeted applications at the highest sensitivity, and targeted applications at the lowest sensitivity, respectively.

The overall weed density increase for the lowest sensitivity from one year to the next appears to follow the exponential growth phase commonly observed in ecological infestations, while the densities for other application methods appear to be in the lag phase (Mack et al. 2000). The increasing weed density could also reduce the subsequent area sprayed at the lowest sensitivity in the following years by increasing the proportion of the field infested. These effects could not be captured in a three-year experiment and should be considered in future experiments.

For the targeted applications, both the highest and lowest sensitivities provided similar reductions in area sprayed ranging from 20% to 90% relative to broadcast applications (Figure 5). The only advantage in the area sprayed for the lowest sensitivity occurred at the early-postemergence application timing, which averaged 41.3% each year compared to 57.9% with the highest sensitivity. In the United States, newly registered and re-registered herbicides considered under the Federal Insecticide, Fungicide, and Rodenticide Act will incorporate the potential for population level impacts to endangered species (Anonymous 2024). During consideration, herbicides may be required to incorporate mitigation strategies to protect endangered species. Utilizing targeted applications is one of the proposed strategies. Both the highest and lowest spray sensitivities providing savings that fall within the medium efficacy classification for Environmental Protection Agency mitigation measures, providing two mitigation points;

however, this research featured a specific herbicide program, and utilizing a different preemergence residual herbicide could alter the savings by increasing the weed density at postemergence applications (Woolard et al. 2025).

Targeted applications at the lowest sensitivity increased soybean yield compared to broadcast applications (Figure 6). Averaged over the years, soybean yielded 4,220 kg ha^{-1}, 4,350 kg ha^{-1}, and 4,480 kg ha^{-1} in broadcast, highest sensitivity, and lowest sensitivity treatments, respectively. The increased yield for the lowest sensitivity treatment is difficult to explain since labeled rates of postemergence herbicides were utilized in all three years. One explanation could be that the higher yield was due to a reduced area sprayed with labeled rates of the postemergence herbicides glufosinate, glyphosate, *S*-metolachlor, and acetochlor. All these herbicides are detoxified through metabolic pathways that require energy expenditures (Breaux 1986; Moldes 2008; Pline 1999), and by targeting herbicides, some soybean plants could have devoted more resources towards development. However, the only difference in the area sprayed between targeted applications was observed at early postemergence, suggesting the early-season applications may be a causal effect (Figure 5).

The 260 kg ha^{-1} increase due to the lowest sensitivity treatment compared to the broadcast may not justify the 198% increase in the Palmer amaranth seedbank over three years with the lowest sensitivity (Figure 5; Table 4), especially considering the limited postemergence herbicide options for northeast Arkansas soybean producers (Carvalho et al. *in review*). If a effective postemergence herbicide is lost due to resistance, the newly introduced herbicide tends to be more expensive, impacting profitability in the future (Kniss et al. 2022; Livingston et al. 2016; Norsworthy et al. 2012). Ultimately, the producer must decide whether the short-term benefits (improved herbicide savings and increased yield) outweigh the risk of herbicide resistance evolution. Future research is needed to determine what is the cause of yield improvement and whether it persists in subsequent years, and to quantify if there is a shift in Palmer amaranth resistance due to targeted herbicide applications.

Based on the total application costs, both targeted applications provided a return relative to broadcast programs at both application timings (Figures 5 and 7). Averaged over the years, targeted applications of all herbicides cost \$140.89 ha^{-1} and \$118.57 ha^{-1} for the highest and lowest spray sensitivities, respectively, whereas the broadcast postemergence program cost \$227.22 ha^{-1}. The lowest sensitivity provided the highest return on investment for the total postemergence costs, which is attributed to greater savings at early postemergence (Figure 5). Utilizing the range of savings from Figure 7, producers adopting this technology at the \$40,000 upgrade cost could expect to pay off the investment by treating 266 ha to 1229 ha if using the highest sensitivity or 218 ha to 909 ha with the lowest sensitivity. At the \$80,000 upgrade cost, the extremes shift to 220 ha and 1273 ha, respectively. At no point did the savings overlap with the broadcast program costs, indicating that utilizing targeted applications with both residual- and postemergence-active chemistries can provide an economic return in soybean production following a broadcast preemergence at planting.

Practical Implications

The weed scientists with the University of Arkansas System Division of Agriculture will continue to recommend broadcast-applying residual herbicides when using targeted applications (Dr. Jason Norsworthy, personal communication). Due to time constraints and the potential to increase the return on investment, producers may still be inclined to target-apply residual herbicides. The research demonstrated here illustrates the ability of postemergence targeted applications to provide similar weed control and improve producer profitability if utilizing the highest sensitivity. Using the lowest sensitivity may have reduced herbicide costs in the short-term, but the increased risk for escapes each year will likely have negative long-term consequences (e.g., increased weed density, potential herbicide resistance, and reduced savings), which will be determined through continuation of this experiment. Both targeted application methods demonstrate the potential for this technology to provide endangered species mitigation points and reduce the environmental loading of pesticides through the reduced area sprayed. Additionally, producers may notice a subtle yield benefit by utilizing targeted applications rather than broadcasting herbicides across the field, but this result may not be reciprocated to different sites of action or in areas with higher weed densities than evaluated here. The latter would likely increase the proportion of the field treated, and additional research is needed to validate these results.

It is important to note that these results may not translate to all soybean production hectares across the United States. This research was conducted in a conventionally tilled, bedded soybean production system, which is typical of the midsouthern United States. Furthermore, the preemergence herbicides included a premixture of pyroxasulfone and flumioxazin, demonstrating excellent Palmer amaranth control out to 28 days after emergence (Houston et al. 2021). Results could be vastly different if using a less or more effective preemergence residual herbicide than evaluated here. Machine settings and nozzle selection may also provide varying results. The sprayer was set to utilize a small low buffer, which dictates how many and how long nozzles are activated to treat a weed. PS3DQ0005 nozzles also provide a 100-degree fan angle with a medium droplet classification at 283 kPa (unpublished data; Anonymous 2018). Utilizing different sprayer setups could impact performance, and more research is needed surrounding buffer and nozzle selections.

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Competing Interests

The authors declare none.

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Table 1. Dates for planting, applications, and harvest.

Year	Planting/preemergence	Early-postemergence	Mid-postemergence	Harvest
2022	May 4	Jun 12	Jun 23	Oct-10
2023	May 18	Jun 6	Jun 20	Oct-04
2024	Apr 23	May 22	Jun 12	Oct-14

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Table 2. List of herbicide treatments for the three-year soybean experiment.

Application timing[a]	Herbicide[b]	Rate	Cost[c]
		g ai ha^{-1} or (% v/v)	\$ ha^{-1}
Preemergence	flumioxazin	71	54.90
	pyroxasulfone	89	-
	paraquat	716	19.37
	nonionic surfactant	(0.25)	2.79
Early-postemergence	glufosinate	657	46.02
	glyphosate	1,120	15.49
	S-metolachlor	1,600	45.22
Mid-postemergence	glufosinate	657	46.02
	acetochlor	1,260	32.47
Total			262.28

[a] Preemergence applications were broadcast-applied at planting, early- and mid-postemergence applications were either broadcast- or target-applied.

[b] Herbicide products: flumioxazin + pyroxasulfone, Fierce® 76 WDG (Valent U.S.A. Corporation, Walnut Creek, CA); paraquat, Gramoxone® SL 2.0 or 3.0 (Syngenta Crop Protection, LLC, Greensboro, NC); nonionic surfactant, Preference® (Winfield Solutions, LLC, St. Paul, MN); glufosinate, Liberty® 280SL (BASF Corporation, Research Triangle Park, NC); glyphosate, Roundup PowerMAX® 3 (Bayer CropScience LP, St. Louis, MO); *S*-metolachlor, Dual Magnum® 7.62 EC (Syngenta Crop Protection, LLC, Greensboro, NC); acetochlor, Warrant® (Bayer CropScience LP, St. Louis, MO).

[c] Costs are based on the calculated 10-year average reported using the Mississippi State Archived Budget Publications from 2016 to 2025 found at: https://www.agecon.msstate.edu/whatwedo/budgets/archive.php. Prices for flumioxazin + pyroxasulfone are based on a 9-year average and acetochlor is based on a 7-year average. Nonionic surfactant is based on the general term surfactant reported in the budgets.

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Table 3. Effect summary for in-season weed counts and area sprayed with targeted applications.[a]

Effect	Counts at application	Misses at application	Area sprayed[b]
Application method	0.0002	< 0.0001	0.0395
Year	< 0.0001	0.0752	< 0.0001
Timing	< 0.0001	0.1587	0.6853
Application method × year	0.0066	01195	0.7816
Application method × timing	0.2127	0.2343	0.0038
Timing × year	< 0.0001	0.0993	< 0.0001
Application method × timing × year	0.3587	0.1074	0.1125

[a] P-values calculated using JMP Pro 18.0 (SAS Institute, Cary, NC) using generalized linear mixed models for counts and standard least squares for area sprayed and misses.

[b] Broadcast treatments excluded from area sprayed due to no variation in the response.

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Table 4. Effect of application method on Palmer amaranth counted from exhaustive germination evaluations.[ab]

Application method	Palmer amaranth density				
	2022	2024		Δ	
	------------------------ Counts m^{-2} -------------------------				
Broadcast	780	1563	b	783	b
Highest sensitivity	569	1645	b	1077	b
Lowest sensitivity	634	2880	a	2246	a
P-value	0.8386	0.0154		0.0024	

[a] Differing letters in a column indicate significantly different means based on Tukey's HSD at $\alpha = 0.05$

[b] P-values calculated using JMP Pro 18.0 (SAS Institute, Cary, NC) using standard least squares.

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Table 5. Effect summary of Palmer amaranth escapes at harvest and soybean yield.[a]

Effect	Escapes at harvest	Soybean yield
Application method	0.0107	0.0117
Year	< 0.0001	< 0.0001
Application method × year	0.4843	0.5046

[a] P-values calculated using JMP Pro 18.0 (SAS Institute, Cary, NC) using generalized linear mixed models for escapes and standard least squares for soybean yield.

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Table 6. Orthogonal contrast of weed counts at the mid-postemergence timing to determine if targeted residual herbicides at early postemergence increase the subsequent weed population.[a]

	Weed density (weeds ha^{-1})[b]	
Contrast	P > |t|	Means
Broadcast vs Highest sensitivity	0.8739	840 vs 989
Broadcast vs Lowest sensitivity	0.0264	840 vs 4310

[a] Orthogonal contrast calculated in the fit model platform.

[b] Weed density was averaged over years and represents the weeds counted at mid-postemergence application minus the weeds missed at early postemergence.

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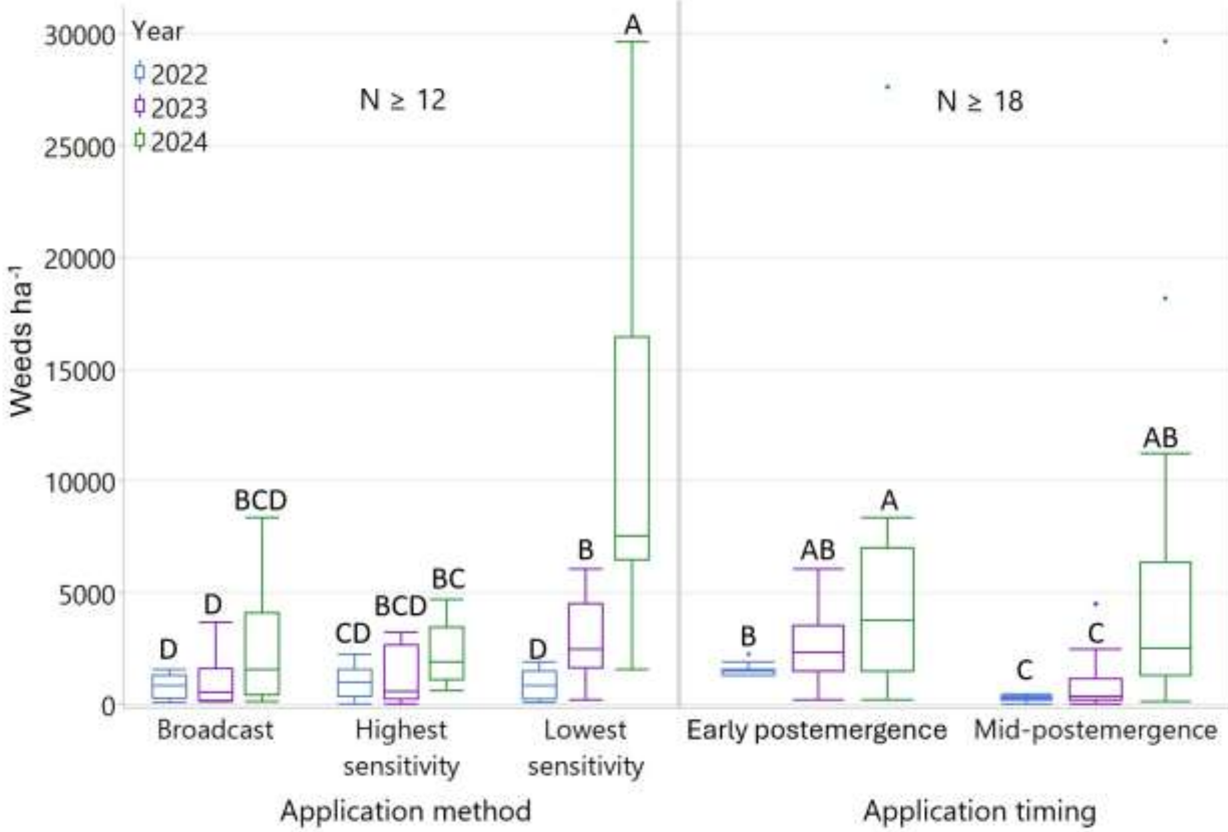

Figure 1. Effect of application method by year interaction (left) and timing by year interaction (right) on weed density averaged over application timing. Box and whiskers are based on observed data. Levels not containing similar letters represent different least square means according to Tukey's HSD at α = 0.05. Figure generated using 'graph builder' within JMP Pro 18 (SAS Institute, Cary, NC).

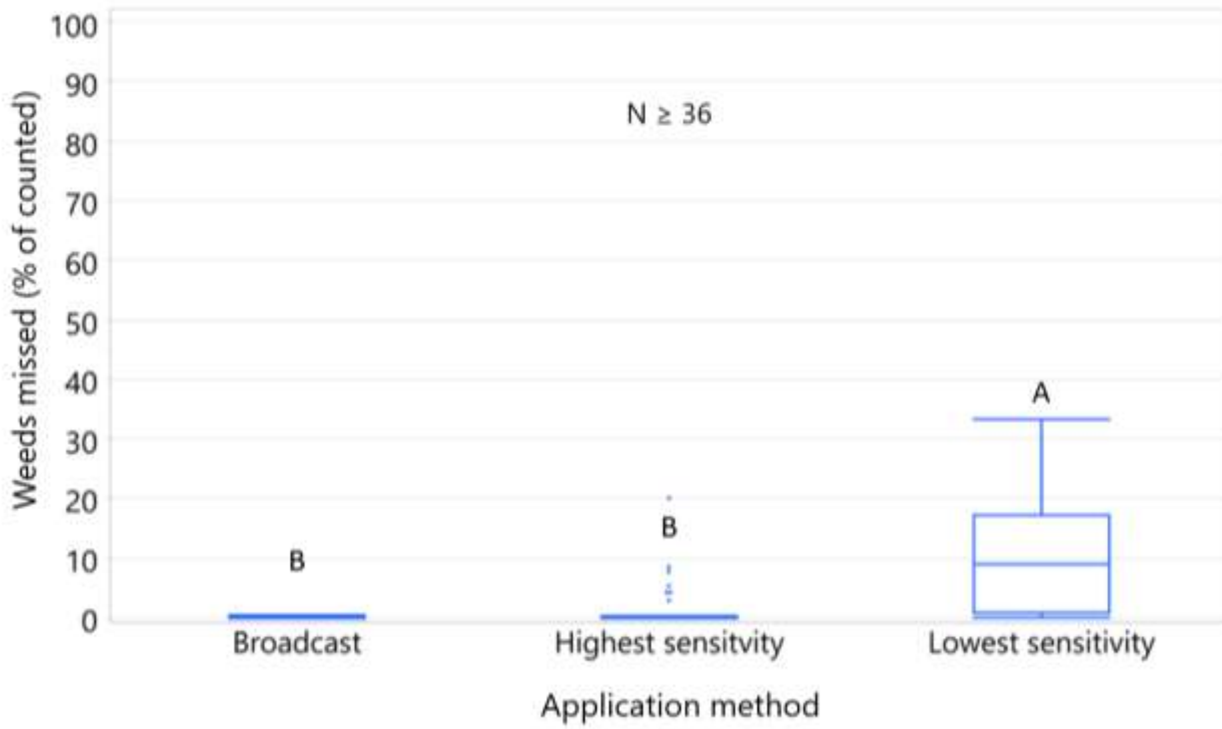

Figure 2. Effect of application method on weeds missed at application ha^{-1} averaged over application timing and years. Box and whiskers are based on observed data. Levels not containing similar letters represent different least square means according to Tukey's HSD at α = 0.05. Figure generated using 'graph builder' within JMP Pro 18 (SAS Institute, Cary, NC).

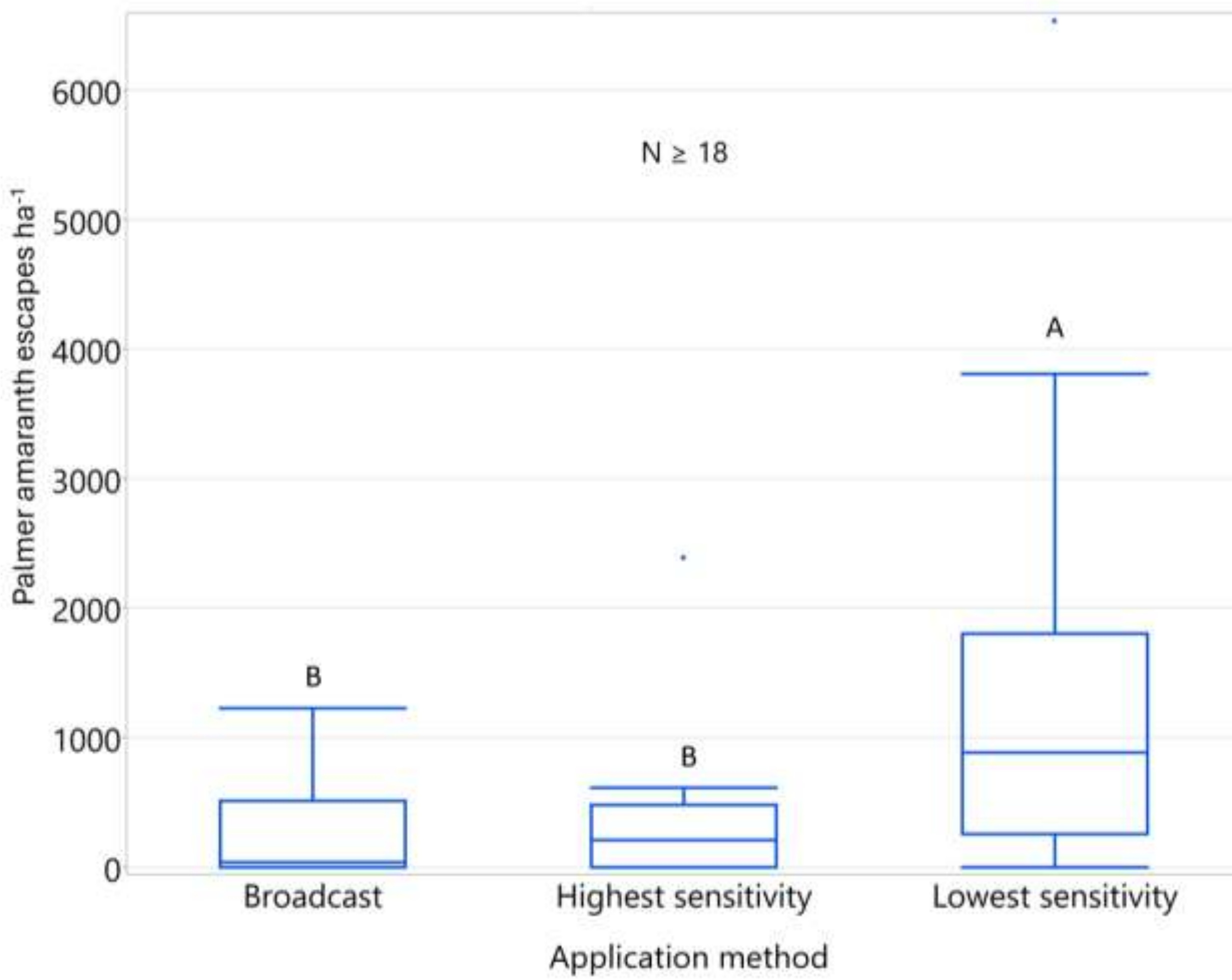

Figure 3. Effect of application method on the proportion of Palmer amaranth escapes, averaged over years. Box and whiskers are based on observed data. Levels not containing similar letters represent different least square means according to Tukey's HSD at $\alpha = 0.05$. Figure generated using 'graph builder' within JMP Pro 18 (SAS Institute, Cary, NC).

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Figure 4. Photographs of the same plot treated with targeted applications at the lowest sensitivity in 2024. Many of the weeds seen at early postemergence were missed, too large to control at mid-postemergence, and became reproductive by harvest.

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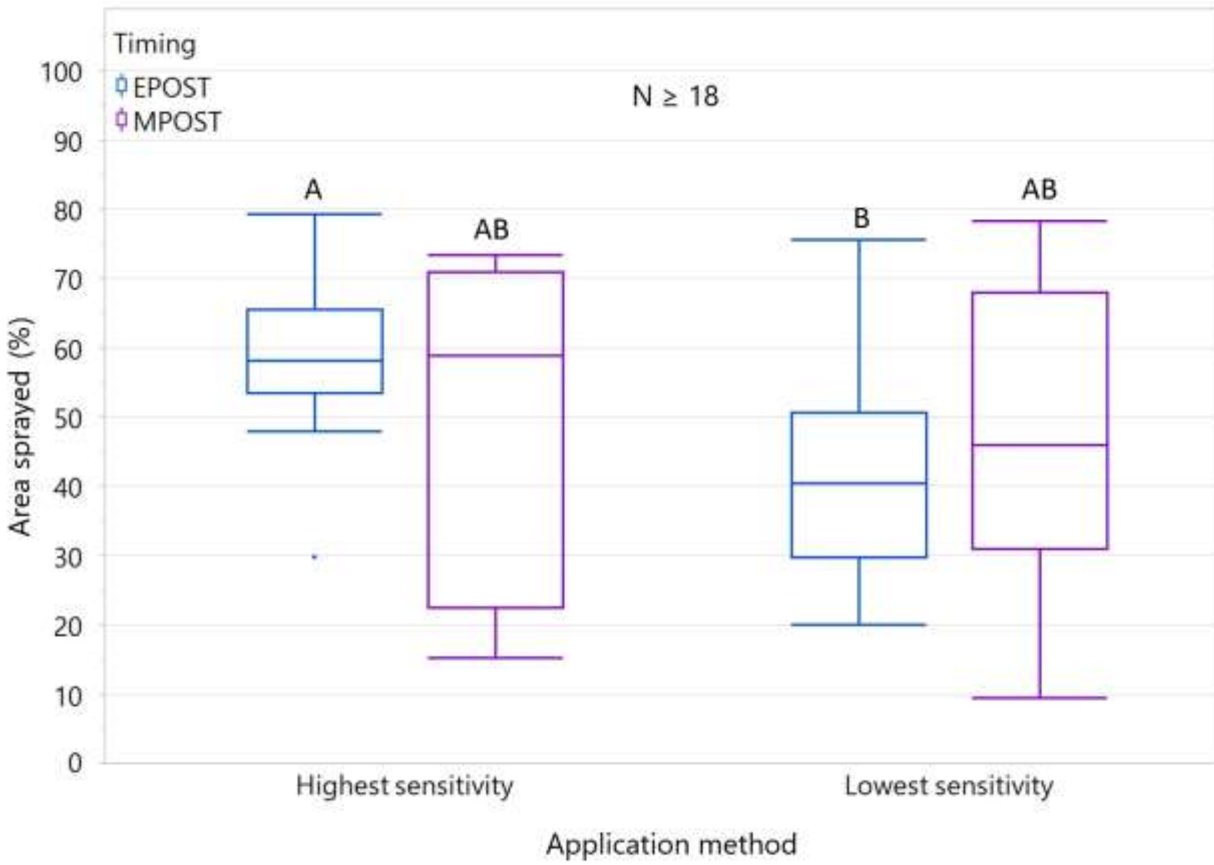

Figure 5. Effect of application method by timing interaction on area sprayed, averaged over years. Box and whiskers are based on observed data. Levels not containing similar letters represent different least square means according to Tukey's HSD at $\alpha = 0.05$. Figure generated using 'graph builder' within JMP Pro 18 (SAS Institute, Cary, NC).

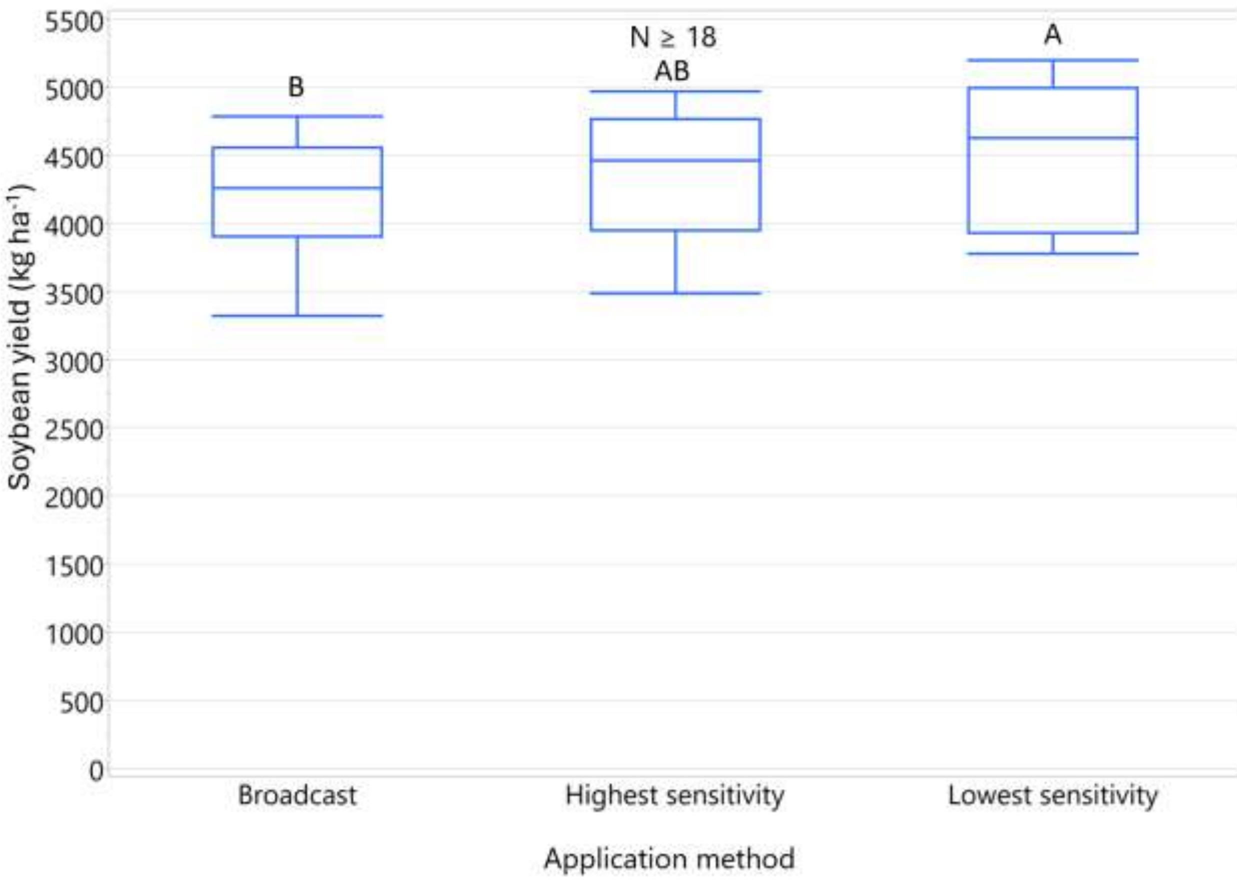

Figure 6. Effect of application method on soybean yield, averaged over years. Box and whiskers are based on observed data. Levels not containing similar letters represent different least square means according to Tukey's HSD at $\alpha = 0.05$. Figure generated using 'graph builder' within JMP Pro 18 (SAS Institute, Cary, NC).

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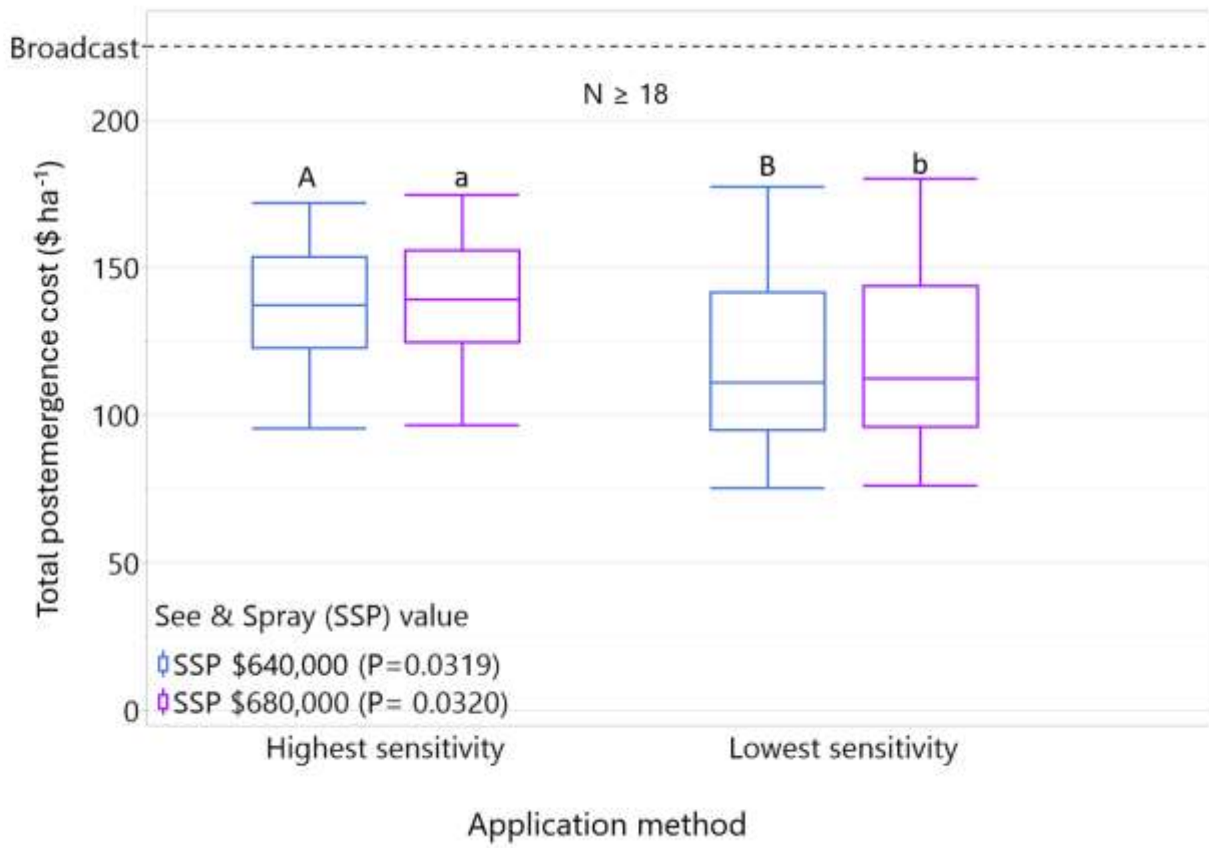

Figure 7. Effect of application method and year on application costs (USD). Application costs account for the 10-year average of herbicide, interest, and labor costs; subscription fees; and equipment cost accounting for efficiency. Broadcast applications are excluded from the figure but are displayed with the dashed line. Assuming a \$600,000 broadcast sprayer valuation, the dashed line represents the cost associated with the total broadcast postemergence herbicide program at \$227.22 ha^{-1}. Box and whiskers are based on observed data. Levels not containing similar letters represent different least square means according to Tukey's HSD at $\alpha = 0.05$. Blue boxes are for a See & Spray Premium machine valued at \$640,000 and are separated using uppercase letters. Purple boxes are for a See & Spray Premium machine valued at \$680,000 and are separated using lowercase letters. Figure generated using 'graph builder' within JMP Pro 18 (SAS Institute, Cary, NC).

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