2,4-D (Enlist One) and Glufosinate (Liberty) Additively Control Common Weeds in South Dakota Soybean Production

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Introduction

Herbicides are recommended to be applied in mixtures to increase application efficiency, spectrum of weed control, and reduce selection pressure on resistant biotypes. Herbicide mixtures can provide activity on various weeds that are antagonistic (decreased control), additive, and synergistic (increased control) (Green 1989). The resulting activity can be an effect of chemical compatibility/incompatibility or the physiology of the weed and/or herbicides (Barbieri et al. 2022). Physiological antagonism or synergism can occur when herbicides with different modes of action are mixed and interact inside the plant negatively or positively, respectively (Meyer et al. 2019; Ou et al. 2018). Since mixtures of unique herbicides are often recommended, understanding how various mixtures of these unique herbicides perform on various weed species under field conditions is critical.

2,4-D (Herbicide Group 4) and glufosinate (Herbicide Group 10), whether applied alone, mixed, or sequentially, will likely become more common for weed management and the commercial availability of herbicide tolerant soybean varieties (i.e., Enlist e3 [tolerant to 2,4-D, glufosinate and glyphosate). 2,4-D is a slow-acting, phloem-mobile herbicide with predominant activity on broadleaf weeds (Grossman 2010). Glufosinate is a fast-acting, contact herbicide with activity on both broadleaf and grass weeds (Corbett et al. 2003; Takano et al. 2020). The mixture of 2,4-D and glufosinate is also a labeled application (Anonymous 2023; Anonymous 2024). Since the physiology of 2,4-D and glufosinate is different, research providing information on whether this mixture provides antagonistic, additive, or synergistic activity on various weed species is critical for effective management (Figure 1). The objective of this experiment was to determine how 2,4-D and glufosinate, when applied alone or mixed, control common weeds and affect soybean yield.

Materials and Methods

Field experiments were conducted in 2023 and 2024 at Beresford (Southeast Research Farm) and South Shore (Northeast Research Farm), SD, for a total of four site-years. The soil at the Beresford location is an Egan-Trent silty clay loam. The soil at the South Shore location is a Kranzburg-Brookings silty clay loam. Natural populations of common lambsquarters, common waterhemp, and velvetleaf occurred at Beresford (two site-years). Natural populations of redroot pigweed and yellow foxtail occurred at South Shore (two site-years). Each site was conventionally tilled prior to planting experiment establishment. Soybean seeds were planted at a density of 160,000 seeds per acre with 30 inch row spacing for all site years. Soybean varieties

Figure 1. Differential injury incurred from 2,4-D (A) and glufosinate (B) on various weeds. Does applying these herbicides mixed affect control (C)?

differed from year and location, but all varieties were selected for local conditions and tolerance to 2,4-D and glufosinate. Soybean varieties used for all site years were resistant to 2,4-D, glufosinate, and glyphosate. Preemergence herbicides were not applied to ensure the maximum weed seedling emergence.

Treatments were arranged as a randomized complete block design with four replications. Individual plots were 10 foot wide × 40 feet long. Herbicide treatments were applied to plots with a CO_2-pressurized backpack sprayer calibrated to deliver 15 gallons per acre with nozzles 20 inches above the target weed height. All weeds were treated at approximately 6 inches in height. All treatments were applied with TeeJet 8003 AIXR spray nozzles. 2,4-D choline (Enlist One, Corteva Agriscience™, Indianapolis, IN) was applied at 32 fl oz per acre with no additional adjuvants. Glufosinate (Liberty, BASF, Raleigh, NC) was applied at 32 fl oz per acre with 8.5 lbs per 100 gallons of ammonium sulfate. When mixed, 2,4-D and glufosinate were applied at the same rates alone but included ammonium sulfate. Clethodim (Select Max [16 fl oz per acre], Valent U.S.A. LLC, San Ramon, California) was applied at 21 days after treatment (DAT) with the same spray parameters described above, but only to the 2,4-D-only treatments for grass weed control. No response variable data were recorded for grass species in these plots.

Weed control evaluations were made using estimates based on a scale ranging from 0% to 100%, where 0% equals no control (i.e., no injury symptoms on any tissue) and 100% equals complete control (i.e., total necrosis). Control evaluations were made 28 DAT.

Soybean was harvested after reaching physiological maturity using a combine, and yield was adjusted to 13% moisture.

Weed control and soybean yield data were subjected to analysis of variance (ANOVA) using the Glimmix procedure in SAS 9.4 (Statistical Analysis Software Institute, Cary, NC, USA) ($\alpha = 0.05$). Herbicide was considered a fixed effect, whereas block and year and their interactions were considered random effects. Year was considered random to allow inferences to be made across broader conditions and locations. Treatment means were separated using Fisher's Least Significant Difference test ($P \leq 0.05$).

2,4-D + glufosinate mixtures were evaluated to determine if the activity was additive, antagonistic, or synergistic 28 DAT using Colby's Method (Colby, 1967). Colby's method calculates an expected control value for an herbicide mixture based on the control of the individual herbicides and the expected control value is compared with the control of the tested mixture. 2,4-D + glufosinate treatments were analyzed using the equation for Colby's method:

$$E = (X + Y) - \left(\frac{xy}{100}\right)$$

where E is expected control (%) of two herbicides applied in a mixture, X is control (%) of X herbicide when applied alone, and Y is control (%) of Y herbicide when applied alone. The expected control was compared with the observed control using a two-sided t-test ($\alpha = 0.05$). If the control was greater than expected, the mixture was considered synergistic, whereas if the control was lower than expected, the mixture was considered antagonistic (Colby 1967). If the observed and expected controls were equal, the mixture was considered additive (Colby 1967). Since 2,4-D does not control yellow foxtail, statistical deviations from the single and mixed applications of 2,4-D and glufosinate can provide evidence of antagonism or synergism (Meyer and Norsworthy 2019).

Results

Common lambsquarters

2,4-D and 2,4-D+glufosinate provided greater control than glufosinate by 12 to 16%, on average (Figure 2). Common lambsquarters control was additive with 2,4-D+glufosinate (Table 1).

Common waterhemp

2,4-D and 2,4-D + glufosinate provided greater control than glufosinate by 26%, on average (Figure 2). Waterhemp was additively controlled with 2,4-D + glufosinate (Table 1).

Redroot pigweed

Glufosinate and 2,4-D + glufosinate provided approximately 10% greater control than 2,4-D, on average (Figure 3). 2,4-D + glufosinate additively controlled redroot pigweed (Table 1).

Velvetleaf

2,4-D, glufosinate, and 2,4-D + glufosinate provided at least 90% control (Figure 2). 2,4-D + glufosinate additively controlled velvetleaf (Table 1).

Yellow foxtail

Glufosinate and 2,4-D + glufosinate did not provide control greater than 62% (Figure 3). 2,4-D+glufosinate and glufosinate controlled and reduced the height of yellow foxtail similarly which suggests that the tank mixture has additive activity (Figure 3). However, control never exceeded 70% suggesting these treatments may not be effective.

Yield

Yield from each location is separated due to different environmental conditions and weed species present. All herbicide treatments yielded similarly and greater than the non-treated control (Figure 4). The yield from 2,4-D-only treatments are likely not true representations of yield, as clethodim was applied to control yellow foxtail and other grass weeds present. Therefore, yield would likely be lower if only 2,4-D was applied to a field with yellow foxtail and/or other grass weed species.

Conclusions

Most 2,4-D and glufosinate treatments provided at least 80% control of the tested broadleaf weeds species, excluding waterhemp, which glufosinate only provided 66% control (Figures 2 and 3). However, when 2,4-D and glufosinate were mixed, control increased to at least 85% for all broadleaf species. Since control of all tested herbicide treatments were poor on yellow foxtail, other herbicides and nonchemical tactics should be implemented where this species infests at high densities. Therefore, 2,4-D + glufosinate is an effective tank mixture to manage common broadleaf weeds in South Dakota soybean production. If grass weeds are present in great densities, other herbicides and tactics should be utilized.

Even though all singular herbicide applications were capable of providing similar control and soybean yield compared to the herbicide tank mixture, applying these herbicides alone is not recommended because it increases selection pressure on resistant weed species. For example, 2,4-D-resistant waterhemp has been confirmed in Nebraska, Illinois, Minnesota, and Missouri (Bernards et al. 2012; Evans et al. 2019; Singh et al. 2024; Shergill et al. 2018). While glufosinate-resistant

Table 1. Control (expected and observed) of common weed species with 2,4-D and glufosinate 28 d after the initial herbicide application in soybean conducted in experiments at Beresford and South Shore, SD, in 2023 and 2024.[a]

Species	Herbicide Treatment	Expected	Observed	P-value
		Control (%)		
Colq	2,4-D+G	99	96	0.5
Cowh	2,4-D+G	96	87	0.13
Rrpw	2,4-D+G	98	96	0.26
Velve	2,4-D+G	100	99	0.8

[a]Abbreviations: 'Colq', common lambsquarters; 'Cowh', common waterhemp; 'Rrrpw', redroot pigweed; 'Velve', velvetleaf; G, glufosinate; 2,4-D+G, 2,4-D + glufosinate.

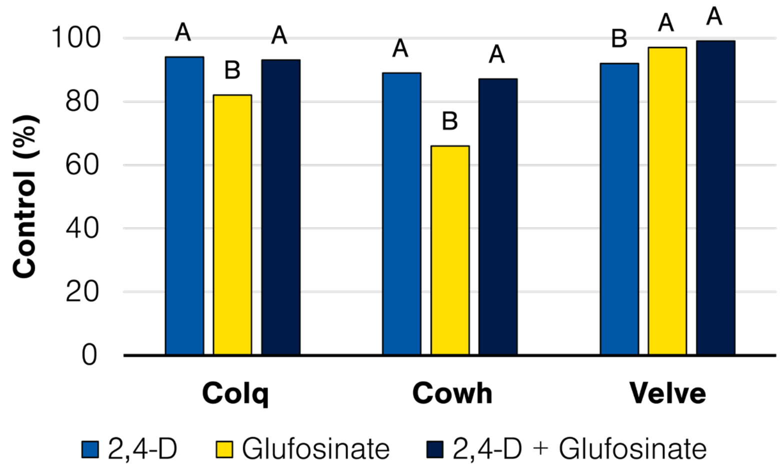

Figure 2. Control of common lambsquarters (Colq), common waterhemp (Cowh), and velvetleaf (Velve) with 2,4-D (32 fl oz per acre), glufosinate (32 fl oz per acre) and 2,4-D + glufosinate at Beresford combined from 2023 and 2024. Bars within weed species that share similar letters are not statistically different.

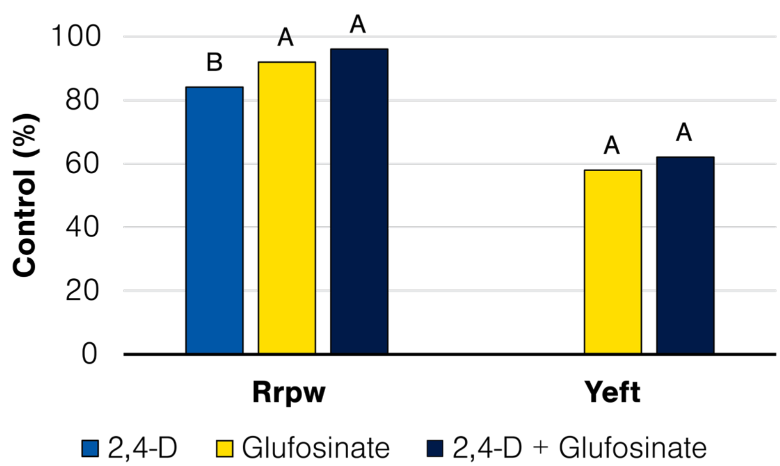

Figure 3. Control of redroot pigweed (Rrpw) and yellow foxtail (Yeft) with 2,4-D (32 fl oz per acre), glufosinate (32 fl oz per acre) and 2,4-D + glufosinate at South Shore combined from 2023 and 2024. Since 2,4-D does not have grass activity, yellow foxtail control was not considered. Bars within weed species that share similar letters are not statistically different.

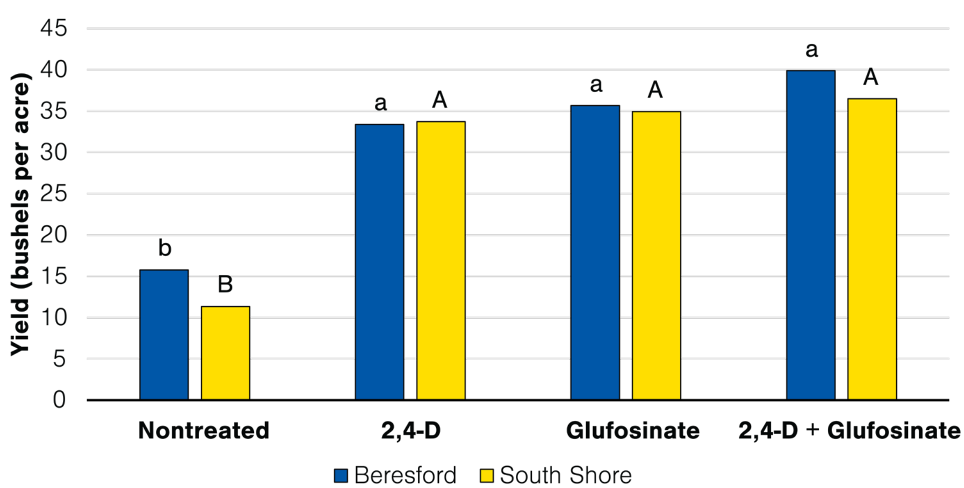

Figure 4. Soybean yield with 2,4-D (32 fl oz per acre), glufosinate (32 fl oz per acre) and 2,4-D + glufosinate at Beresford and South Shore combined from 2023 and 2024. Bars within herbicide that share similar letters are not statistically different.

waterhemp has not been confirmed, control failures are often reported. Therefore, mixing herbicides can help increase the longevity of the remaining effective herbicides in South Dakota (i.e., 2,4-D and glufosinate).

Herbicides were applied to weeds at approximately 6 inches in height to tease out performance differences of each treatment. These herbicides alone and in mixture should be applied to weeds 4 inches in height or less to increase effectiveness. The surviving weeds at the end of the season likely produced seeds that will have to be managed in future growing seasons (Jones et al. 2024; Scruggs et al. 2021). In addition, preemergence herbicides were not used in this experiment to ensure multiple weed species were present. Weed control and soybean yield would be greatly improved with the addition of a strong preemergence herbicide program

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