Cereal rye cover crop, PRE emergence herbicide fate, and pigweed residual control:

Considerations learned from a multi-state field study

Extension
UNIVERSITY OF WISCONSIN-MADISON

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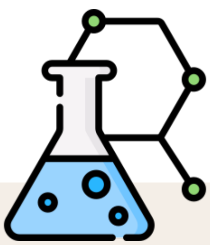
The adoption of cereal rye (*Secale cereale*) cover crop has triggered the interest of farmers as an additional tool for pigweed (waterhemp [*Amaranthus tuberculatus*] and Palmer amaranth [*A. palmeri*]) management in soybean production systems. Along with interest in this practice, there have been many questions about how cereal rye can impact other weed management practices, such as the fate of PRE-emergence (PRE) herbicides in the soil when applied over high cereal rye biomass.



What is herbicide fate?

Herbicide fate is the combination of processes that an herbicide molecule undergoes after leaving the spray tip and is submitted to environmental conditions. We can also think of fate as the journey that an herbicide undergoes in the environment prior to and after reaching its target. Such processes are highly dependent of environmental conditions following application.

Some of the processes that can dictate an herbicide's fate or journey are succinctly described in Figure 1. In the case of a PRE herbicide, the target is the soil, so it can enter the soil solution and be absorbed by germinating weed seeds or emerging seedlings to provide weed control **— PRE herbicides are inactive if not in the soil solution.** This is where spraying PREs over cereal rye biomass can become complicated. The cover crop biomass (also true for other plant residues) can intercept the herbicide molecule and prevent it from reaching its target (the soil). Basically, PRE herbicides have to go the extra mile to reach the soil compared to a tillage-based system. An additional iteration of this system (PRE herbicides and cereal rye biomass) is the difference between spraying PRE herbicides over dead versus living cereal rye biomass. Applying a PRE herbicide over living cereal rye has become more common with the adoption of the planting green system **— when farmers terminate the cereal rye at or after soybean planting to optimize cereal rye biomass accumulation for effective weed suppression**. If applied over living cereal rye, one might hypothesize that the cover crop can absorb the PRE herbicide and contribute to herbicide losses in this system.

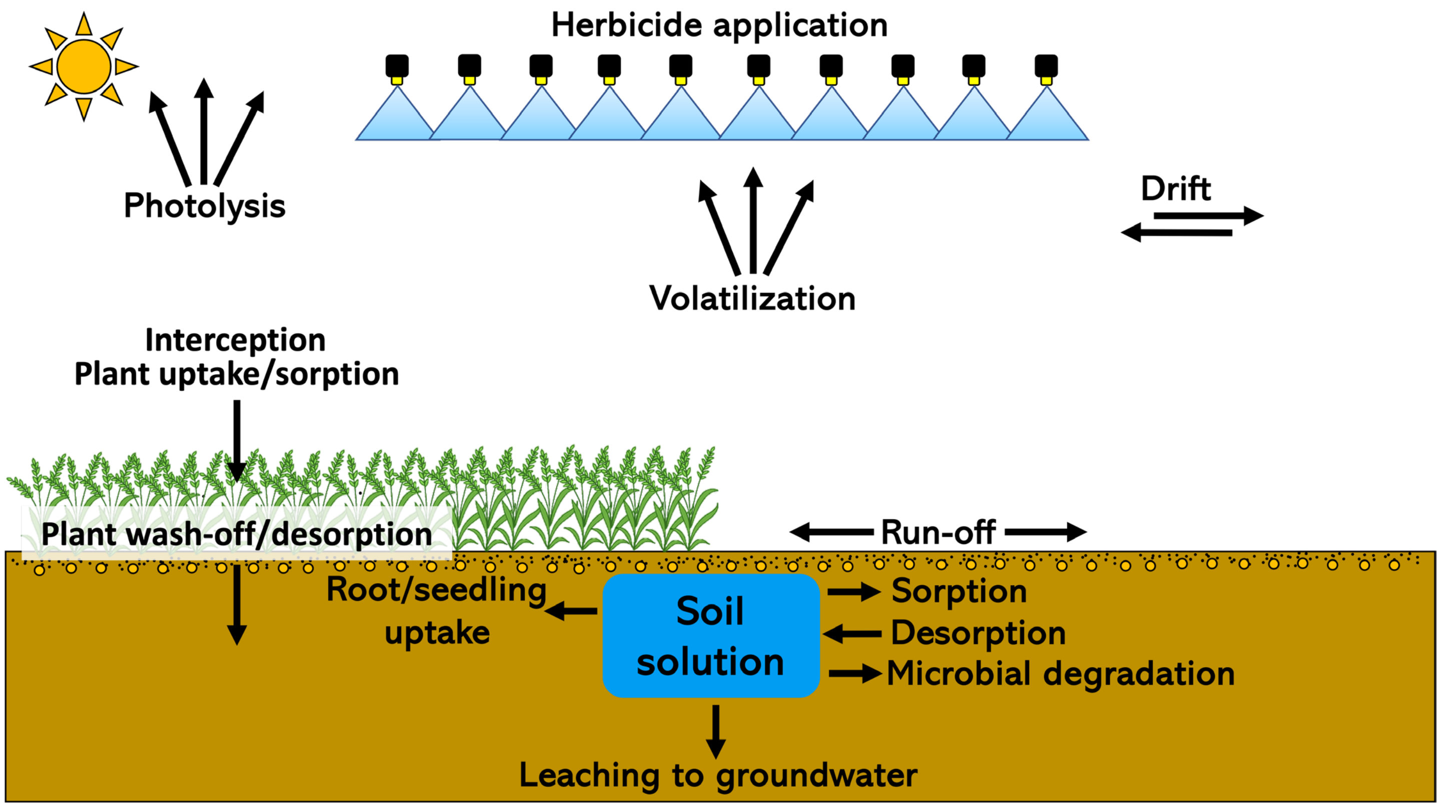


Figure 1. Illustration of some of the processes that can dictate the fate of PRE herbicides in the environment.

We conducted a field study in four locations across the U.S. (Illinois, Kansas, Pennsylvania, and Wisconsin) in 2021 and 2022 to tackle how planting soybean green can impact PRE herbicide fate in the soil and residual pigweed control. Here's the summary of treatments evaluated:

- Cover crop management practices.
    - **No-till** – no cereal rye, only corn stubble from the previous year.
    - **Cereal rye early terminated** ("CC early term") – cereal rye was chemically terminated with glyphosate on average 12 days before soybean planting/PRE application.
    - **Cereal rye planting green** ("CC plant-green") – cereal rye was chemically terminated with glyphosate at soybean planting/ PRE application.
- PRE herbicide program.
    - **No PRE.**
    - **Yes PRE** (pyroxasulfone + flumioxazin [Fierce EZ @ 6 fl oz/A]).

We terminated the cereal rye and sprayed the PREs using a CO_2 backpack sprayer at 15 GPA. To evaluate how the cover crop management practices impacted PRE herbicide fate, we collected soil samples at 0, 7, and 21 DAT (days after treatment/PRE application) to quantify flumioxazin and pyroxasulfone concentration in the soil (Figure 2).

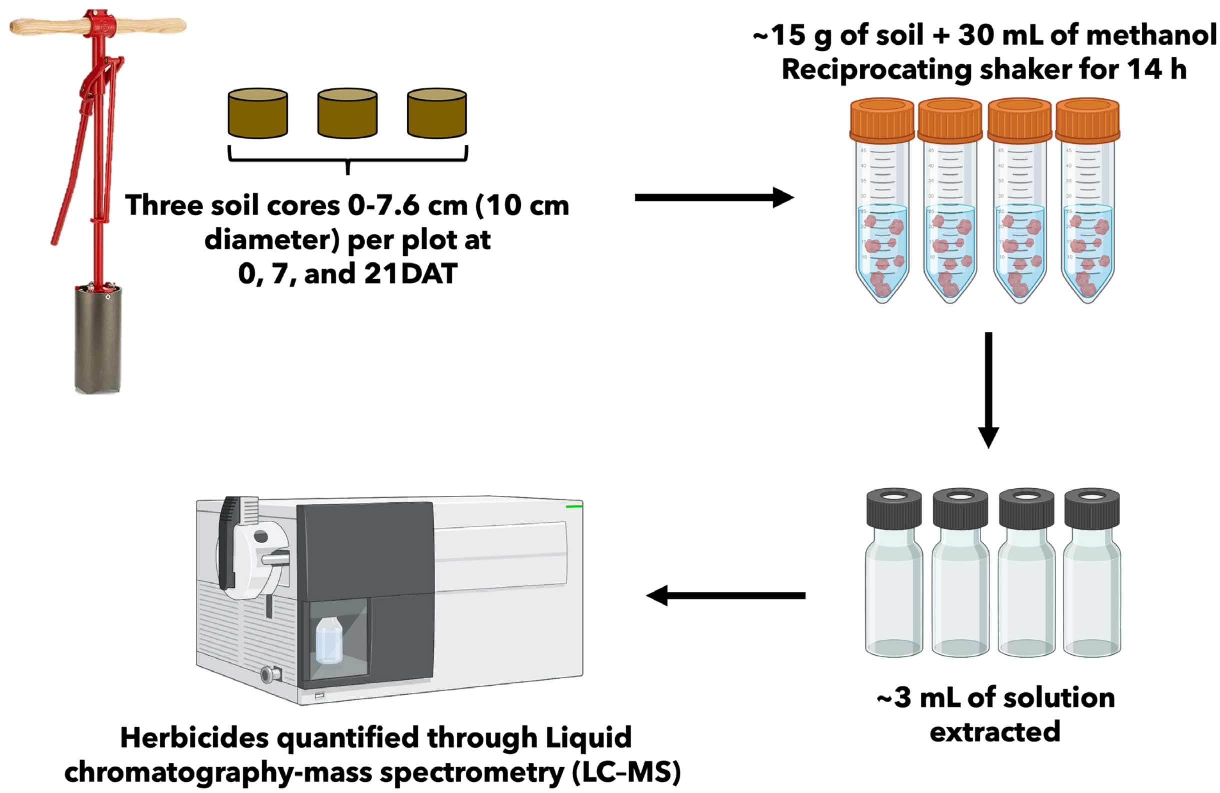
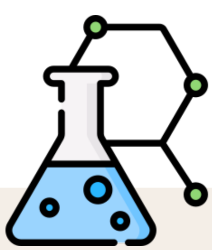


Figure 2. Illustration of the methodology adopted for soil sampling and herbicide quantification.



What are herbicide physicochemical properties?

Herbicide physicochemical properties are intrinsic characteristics of herbicides that are related to their physical and chemical nature. Such properties determine how herbicides interact with the environment, plants, and other substances. Some of these properties are solubility, vapor pressure, dissociation constants (pKa and pKb), partition coefficients (Kow and Koc), and half-life.

Figure 3 illustrates the main findings of our study. It shows the average pyroxasulfone and flumioxazin concentration in the soil over time (0, 7, and 21 DAT) under the different cover crop management practices. There are three main takeaways from Figure 3.

1. The ***first takeaway*** is that the concentration of both herbicides decreased over time (from 0 to 21 DAT) in all treatments. This was expected given the processes that PRE herbicides undergo following application (Figure 1), which results in the dissipation of the herbicide molecules from the environment.

2. The ***second takeaway*** is the difference between the two herbicides. Flumioxazin concentration constantly decreased over time in all management practices. However, pyroxasulfone concentration in the two cereal rye treatments, especially in the early termination, showed an intriguing trend, with its concentration increasing from 0 to 7 DAT and then decreasing from 7 to 21 DAT (Figure 3). This observation brings us to a second important component to understanding herbicide fate in the soil: herbicide physicochemical properties.

All herbicides undergo most of the processes illustrated in Figure 1. However, some molecules can be particularly sensitive to a specific process, given their physicochemical properties. For example, herbicides with high vapor pressure are more susceptible to volatilization than molecules with low vapor pressure. Thus, incorporation (mechanical or irrigation) is essential to move the herbicide from the soil surface into the soil solution where it will be less affected by volatilization. In the case of pyroxasulfone and flumioxazin, the two molecules are fairly similar, but pyroxasulfone presents a slightly higher water solubility and half-life, and a lower vapor pressure than flumioxazin (Table 1). These properties likely favored pyroxasulfone stability in the environment once intercepted by the cereal rye biomass and its movement (wash-off) from the biomass to the soil with rainfall following application to a greater extent than flumioxazin. Thus, explaining why there was a peak in pyroxasulfone concentration from 0 to 7 DAT (Figure 3).

Table 1. Compiled of distinctive pyroxasulfone and flumioxazin physicochemical properties. Adapted from Shaner (2014[1]).

Herbicide	Solubility	Vapor pressure	Half-life
Pyroxasulfone	3.49 mg/L (20 C)	2.4×10^{-6} Pa	16-26 days
Flumioxazin	1.79 mg/L (25 C)	3.2×10^{-4} Pa	11.9-17.5 days

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The ***third takeaway*** is the main message of this study and shows that the cereal rye biomass intercepted pyroxasulfone and flumioxazin during PRE application and lowered their concentration in soil compared to no-till at all sampling timings (Figure 3). In a different study, we measured herbicide spray deposition and coverage at the soil level and observed that the cereal rye biomass intercepts a significant portion of spray droplets during PRE application. Details can be found in Nunes et al. (2023). Despite the difference between no-till and the two cereal rye treatments in the concentration of both herbicides in the soil, our data do not indicate that spraying PRE herbicides over living cereal rye biomass (planting green) was more detrimental to herbicide fate than when applying over dead biomass (early termination). We believe that biomass level (ground coverage) plays a bigger role in herbicide interception and subsequent concentration in the soil than the biomass's state (dead or alive). Figure 4 illustrates pyroxasulfone and flumioxazin concentrations in the soil at 0 DAT as a function of cereal rye biomass at termination. As we can see, there is a linear reduction in the concentration of both herbicides in the soil as the cereal biomass increases, which perfectly illustrates the role of biomass level on PRE herbicide interception and concentration in the soil.

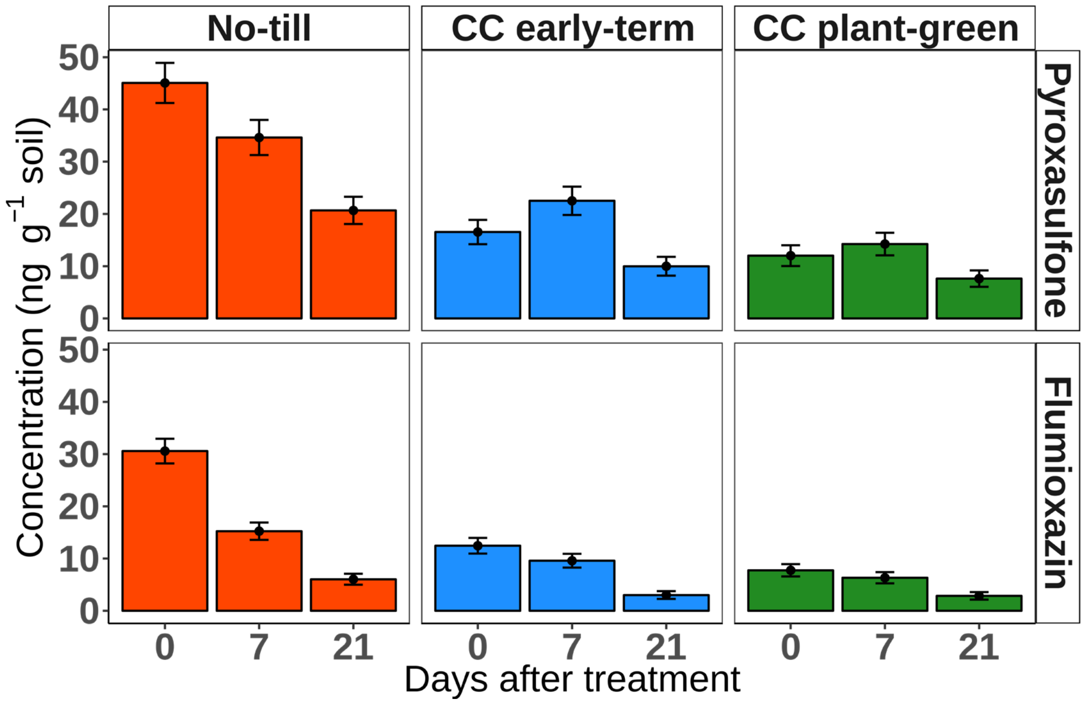

Figure 3. Pyroxasulfone and flumioxazin concentration in the soil over time under different cereal rye management practices. Average of eight site-years of data. Error bars indicate the standard error of means.

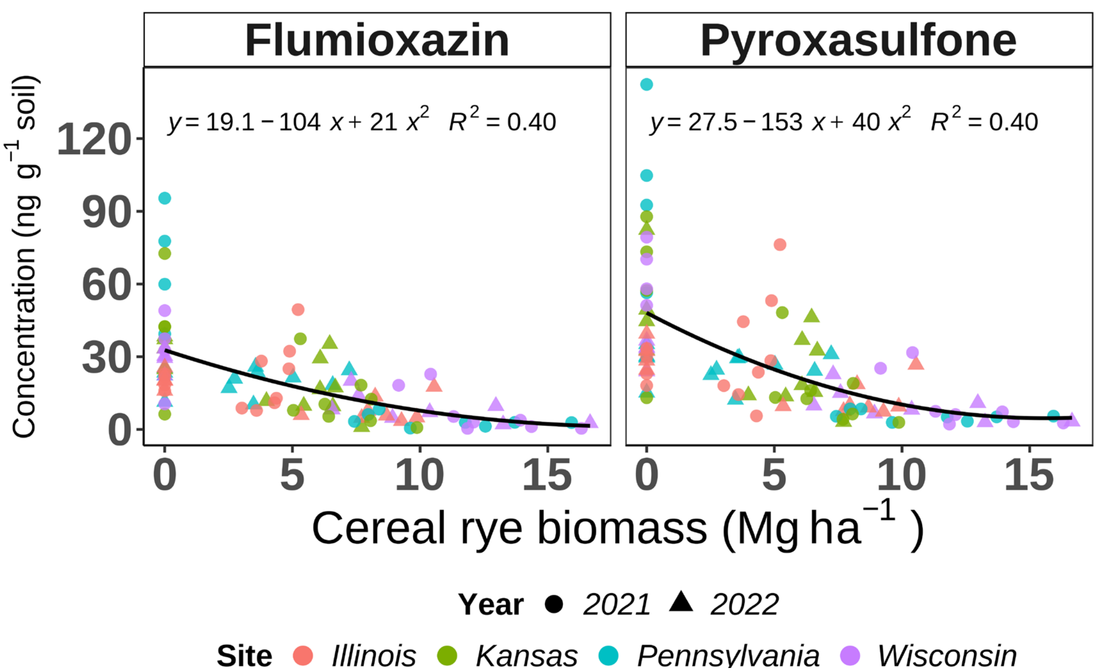

Figure 4. Flumioxazin and pyroxasulfone concentration in the soil at 0 DAT as a function of cereal rye biomass at termination.

As we have learned so far, herbicide fate is a complex combination of processes, herbicide physicochemical properties, and environmental conditions. Despite all that complexity, we want to use an illustration to facilitate our understanding of the impact of cereal rye biomass on PRE herbicide fate. Figure 5 is a simplistic representation of this system and illustrates a field of standing cereal rye sprayed with a PRE herbicide. Based on what we learned from this study and previous literature, we can say that following application, a PRE herbicide can be portioned into three main pathways for their fate:

- **Herbicide not intercepted:** this is the portion of herbicide that leaves the spray tip and goes straight to the soil without being intercepted by the cereal rye. Ideally, this is our goal when spraying a PRE. Place the herbicide in the soil with minimum interception or off-target movement.
- **Herbicide intercepted:** this is the portion of herbicide that is intercepted by the cereal rye biomass during application. Once intercepted, the herbicide can follow two main pathways:
    - **Move to the soil with rainfall after application.** It is desirable to have about 1" of rainfall/irrigation within the first week following PRE application to wash-off the intercepted herbicide from the biomass to the soil. The longer the herbicide remains over the biomass, the longer it will be subjected to processes that dictate its fate.
    - **Remain attached (adsorbed or absorbed) to the cereal rye biomass.** Although PRE herbicides can be washed off from crop residue to the soil with rainfall/irrigation, there is a limit to how much herbicide can be extracted once adsorbed or absorbed by crop residues. A portion of the intercepted herbicide is always expected not to be removed from the cereal rye biomass, regardless of precipitation level[2]. The portion that remains over the cereal rye biomass is highly subjected to dissipation processes such as photodegradation, volatilization, and microbial degradation.
- **Herbicide loss during application:** PRE herbicides are also subject to losses due to drift and off-target movement during application or other dissipation processes that can cause herbicide loss prior to reaching the target (i.e. volatilization).

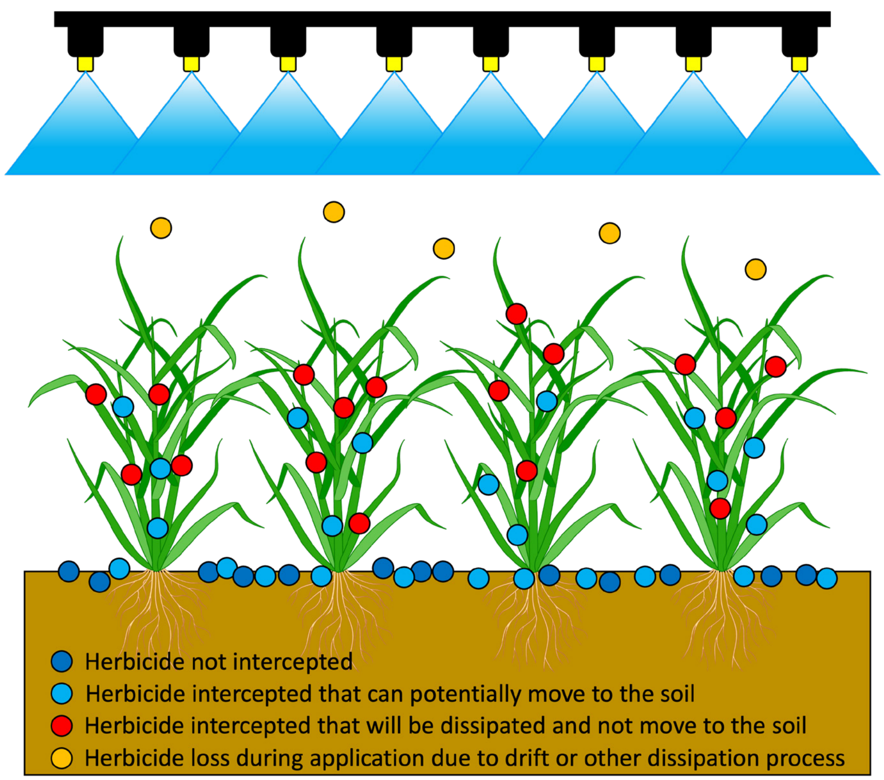

Figure 5. Illustration of the impact of cereal rye biomass on PRE herbicide fate.

So far, we covered what we learned about herbicide fate from this study. But a common question that we receive whenever we present these data is, **"What about residual weed control? Does the lower PRE herbicide concentration in the soil affect residual weed control?"**. From a management standpoint, the answer is NO. Our data do not suggest a loss in residual pigweed control by the time we triggered our POST-emergence (POST) herbicide application (20% of pigweed plants ~4" in height). Figure 6 shows pigweed density at the time of POST application under the different cereal rye management practices without and with the PRE herbicide application. Basically, we have two completely different situations, without and with the use of the PRE herbicides. When we **did not spray** the PRE herbicides, the two cereal rye treatments reduced pigweed density compared to no-till. Cereal rye is effective at suppressing pigweeds. Conversely, when we **sprayed** the PRE herbicides, pigweed density was similar across cereal rye management practices. In this situation, the PRE herbicides carried most of the weight controlling the pigweeds, and the cover crop did not seem to compromise their efficacy. We can also observe that the planting green treatment without the PRE herbicide program resulted in a pigweed density similar to all other management practices with PRE. This illustrates the benefit of delaying cereal rye termination until soybean planting when it comes to pigweed suppression.

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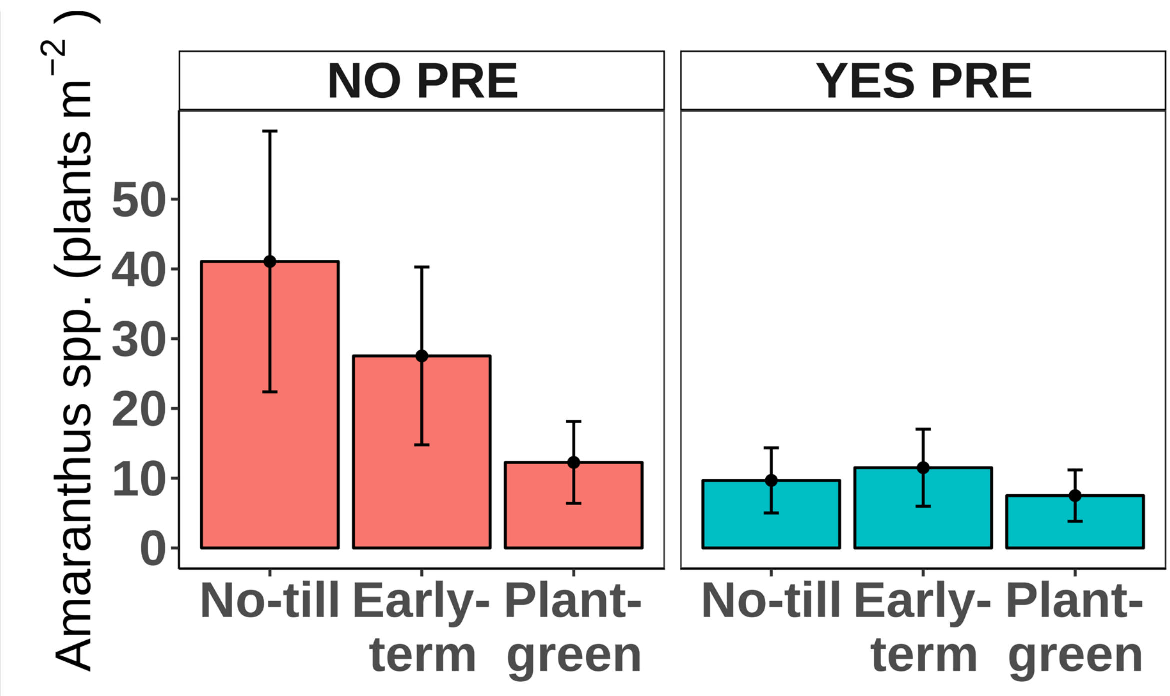

Figure 6. Pigweed density at the time of POST herbicide application under different cereal rye management practices without and with the use of a PRE herbicide program (pyroxasulfone + flumioxazin). Error bars indicate the standard error of means.

In summary, we can conclude that although cereal rye biomass reduced the concentration of PRE herbicides in the soil, but residual pigweed control was not negatively affected by the combination of both practices. This is good news for those interested in integrating cereal rye and PRE herbicides as part of their pigweed management program. Controlling pigweed species is a game of numbers in many aspects, and when it comes to integrating management practices, the more, the better!

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Citation for original manuscript

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