Title: *Developing proactive herbicide resistant weed management strategies for no-till soybean*

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Overview. Recent studies have shown that integrating cover crops into no-till grain crop rotations can improve suppression of problematic glyphosate-resistant weeds, including *Amaranthus* species and horseweed. In Pennsylvania, cover crops are increasingly integrated into annual grain crop rotations to provide multiple ecosystem services, including improved soil quality, maintenance of nutrient and water cycling, and enhanced biotic pest regulation. These trends signal a unique opportunity to design cover cropping tactics that are guided by an understanding of the processes that select for herbicide resistance in no-till production systems. There is currently considerable interest in 'planting green' in no-till crop production, which describes the management practice of no-till planting summer annual cash crops into actively growing cover crops. Interest in 'planting green' is primarily driven by long-term soil health goals but has important implications for herbicide-resistance management. Cereal rye and winter wheat are typically used before no-till soybean and 'planting green' tactics extend the cover crop growing season window by delaying termination until soybean planting. Previous studies have demonstrated that delayed termination of cereal rye results in greater above biomass production and surface mulch persistence. Cover crop surface mulch influences weed life cycles via attenuation of germination cues and resource exclusion during the seedling emergence and establishment phase. Improving weed suppressive effects of surface mulch has the potential to reduce weed densities and size (i.e., height) at time of herbicide exposure, thereby increasing herbicide efficacy and reducing selection pressure for resistance.

Integrated research and extension-education is needed to identify integrated weed management tactics that increase herbicide efficacy and reduce selection pressure for herbicide resistance.

Experiment 1. Horseweed control options within a cereal rye cover crop

Fall and early spring horseweed (*Erigeron canadensis* L.) management is increasingly recommended in no-till systems within the Northeast region. Herbicide applications and cover crops can both provide horseweed suppression in the fall and spring, but few guidelines are available for integrating these control tactics. In a experiment from 2018 to 2019, fall- and spring- applied herbicides were evaluated in a fall-sown cereal rye (*Secale cereale* L.) cover crop to quantify differences in glyphosate-resistant horseweed control levels and cereal rye biomass production at Penn State's Russell E . Larson Agricultural Research Center in Rock Springs, PA.

Cereal rye was sown at 67 kg ha^{-1} on September 27 and fall and spring herbicides were applied on October 19 and April 10, respectively. Applications were made with a hand-held boom that delivered 140 L ha^{-1}. Herbicides included 2,4-D ester at 560 and 1120 g ai ha^{-1}, dicamba at 280 g, sulfentrazone plus metribuzin premix at 379 g, and chlorimuron plus tribenuron premix at 46 g. The premix treatments were tank-mixed with 2,4-D ester (560 g). At the fall application timing, horseweed ranged from cotyledons to 1.5 cm in rosette diameter and cereal rye was 8 to 10 cm tall (1-2 tillers). At the spring application timing, horseweed rosette diameter ranged from

1.5 to 5 cm and cereal rye was 8 to 15 cm tall (7-12 tillers). Prior to soybean planting (May 15), rye biomass and horseweed density were quantified.

Cereal rye biomass in the untreated check was 3,175 kg ha^{-1} at termination. Herbicide treatments did not affect cereal rye biomass production in comparison to the untreated check, with the exception of sulfentrazone + metribuzin, which resulted in lower cereal rye biomass in the fall (2,387 kg ha^{-1}) and spring (2,266 kg ha^{-1}) treatments. Relative to the untreated check, horseweed density was significantly reduced (93 to 98%) in all herbicide treatments except for spring applications of 2,4-D applied alone at the low rate (560 g ai ha^{-1}) and in combination with chlorimuron + tribenuron, which resulted in 68 and 79% horseweed population reductions, respectively.

Results of our first experimental year suggest that integrating a rye cover crop with fall- or spring- applied herbicides can be an effective tool to control horseweed in no-till systems. Our results also suggest that 2,4-D applied at a low rate (560 g ai ha^{-1}) in the spring may not be an effective option for horseweed control regardless of additional suppression from cereal rye competition. Sulfentrazone + metribuzin reduced rye biomass following fall and spring application timings, which may limit horseweed suppression benefits from surface rye mulch following termination.

Experiment 2. Cereal rye seeding rate effects in planting green soybean production

In agronomic no-till cropping systems, there is an increased interest in planting green to improve soil health. Planting green is a management practice where cover crop termination is delayed until at or after cash crop planting. Growers use different cover crop species, seeding rate, termination-timing, and roll-plant tactics when adopting this practice. We are interested in exploring the effects of planting green tactics on weed population dynamics and their impact on herbicide resistance management goals. We conducted a field experiment at Rock Springs, PA (RELARC) in 2018-19 using a RCBD with four replicates. Treatments included four cereal rye seeding rate: 0, 51, 101, 135 kg/ha.

Dicamba-tolerant soybeans were planted 1 d prior to a cover crop burndown herbicide application (glyphosate + dicamba) using a no-till planter equipped with integrated ZRX rollers. Aboveground cereal rye biomass was harvested one week prior to termination. Horseweed (*Erigeron canadensis*) density and height were recorded just prior to planting and a post-emergent (6 WAP) herbicide application. Large crabgrass (*Digitaria sanguinalis*), redroot pigweed (*Amaranthus retroflexus*), and common lambsquarters (*Chenopodium album*) density and height were recorded at post-emergent herbicide application timing within established artificial weed seedbanks.

Excluding the fallow control, rye biomass at termination did not differ across seeding rate treatments. Horseweed and summer annual weed densities were significantly reduced in all treatments compared to the fallow control. The distribution of redroot pigweed heights at the time of post-emergent applications included individuals that exceeded 15 cm in each treatment with exception of the 101 kg/ha seeding rate. Total late season weed biomass was significantly lower in seeding rate treatments compared to the fallow control treatment but did not differ in pairwise comparisons. Our first-year results suggest that planting green tactics can contribute to proactive herbicide resistance management goals even at low, and economically feasible, cereal rye seeding rates. Future work will include replication of the experiment and a complementary field experiments to further contrast the impacts of planting green tactics on herbicide resistance management goals.

Experiment 3. Reducing herbicide inputs in planted green soybean production

Planting green was integrated into the Dairy Cropping Systems Project in fall of 2018 as an integrated weed management tactic. Planting green is a practice where cover crop termination is delayed until at or after cash crop planting. Treatments include a standard cover crop termination (early killed) and planting green practice. The treatments were compared in a split-plot design with four replicates. The cover crop in the standard cover crop termination treatment (early killed) was terminated 3 weeks prior to soybean planting. The cover crop in the planting green treatment was terminated on the same day as soybean planting. Cereal rye was drilled at 135 kg ha^{-1} in both treatments on October 17, 2018. Artificial weed seedbanks of approximately 400 common lambsquarters (*Chenopodium* album) seeds, 800 redroot pigweed (*Amaranthus* retroflexus) seeds, and 200 large crabgrass (*Digitaria* sanguinalis) seeds were established in a 1 m^2 microplot within each plot. Early killed plots were sprayed with 32 fl oz/ac of glyphosate (Roundup PowerMax) and 16 fl oz/ac of 2-4,D ester on April 30, 2019. Rye biomass samples were collected just prior to termination and soybeans were planted using a no-till planter equipped with a ZRX integrated roller system on May 22, 2019. One day after planting, both treatments were sprayed with 22 fl oz/ac of Roundup PowerMax and early killed plots were sprayed with 3.75 fl oz/ac of Fierce on May 22, 2019. The artificial weed seedbanks were excluded from the Fierce pre-emergence herbicide application. Summer annual weed density and heights from the artificial weed seedbanks were recorded on July 2, 2019. Late season weed biomass samples were collected randomly within each plot on August 15, 2019. All biomass was dried and weighed. Soybeans were harvested on October 11, 2019. Data was analyzed in R (v. 3.6.1) with treatment as a fixed effect and block as a random effect. Analysis of variance was used to test rye biomass, weed densities, weed biomass, and soybean yield responses to treatments. Treatment means were considered significantly different at $P \leq 0.05$.

Our data shows that planting green significantly increased rye biomass at soybean planting (**Figure 1**). Summer annual weed density was significantly reduced (**Figure 2**) and summer annual weed heights decreased in planting green compared to the early killed treatment (**Figure 3**). Both early killed with pre-emergence herbicide application and planting green treatments resulted in less than 10 kg ha^{-1} of late season weed biomass and were not statistically different. Soybean yield was not significantly different between treatments. There was support for our hypotheses for planting green effects on summer annual weed population dynamics, late season weed biomass, and soybean yield. Our first-year results demonstrate that delaying cereal rye termination will increase rye biomass and surface mulch when rolled at soybean planting. The surface residue can alter weed germination cues and provide a physical barrier that must be penetrated for successful weed establishment. Since planting green produced more rye biomass, factors that limit germination and establishment may be intensified when compared to the early killed treatment, explaining observed differences in summer annual weed density and height. The higher rye biomass in the planting green treatment permitted a reduction in herbicide inputs while providing weed sduppression that was not different when compared to the early killed plots.

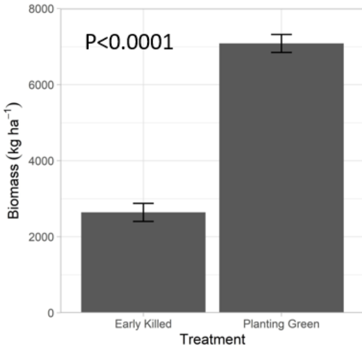

Fig 1.

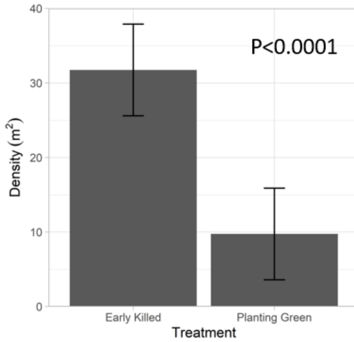

Fig 2.

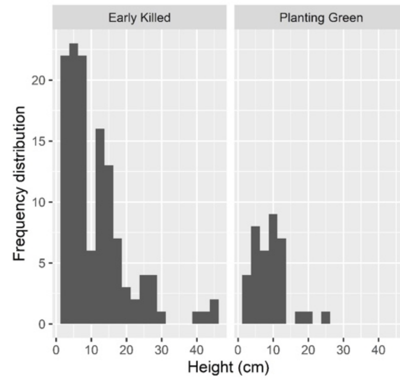

Fig 3.

On Farm Trials: On-farm strip trials focusing on reduced residual herbicide use in planted green soybean were conducted in York, Mercer and Susquehanna counties. Due to weather conditions, the Susquehanna trial was not successfully implemented. Replicated strips were implemented at the farm of John Johnson (Stewartstown, PA; York Co) in 15" no-till soybean, which was planted green into cereal rye at the early heading stage. Replicated strips compared weed responses with and without residual herbicides (Prowl + metribuzin). Weed densities and heights were evaluated just prior to a post-emergence application of glyphosate. Marginal differences in weed densities were observed between treatments but weed heights, including redroot pigweed, were generally higher in no-residual plots. Planting green concepts and implications for herbicide resistance management were discussed at the PA Soybean Board sponsored regional soybean workshop hosted at the Johnson farm in September 2019. A similar trial was implemented at the farm of Rob Glenn in Mercer PA, where the residual herbicide program included Valor and cereal rye was terminated near the boot stage. Due to relatively low weed pressure, few treatment differences were observed.

Summary. *Replication of these studies is needed prior to development and communication of best management practices (BMPs). Consequently, we will continue to advance this research beyond the PA Soybean Board funding period.* No-till soybean producers continue to be interested in BMPs for optimizing weed suppression with cover crops and our research program is providing leadership in this area at a state, regional, and national level. The table below provides a summary of extension-outreach activities and products that highlighted the PSB funded research in the past year.

Extension-Outreach	**No. events**	**No. of participants.**
PSU Winter Extension Mtg	4	300
PSU Field Crop News	1	na
PA Field day (or) workshop	5	200
Regional CCA/Producer Conference	2 (PA & NY)	200
Professional Conference (Paper or Poster)	3	na
Northeast Cover Crop Council (regional; invited)	1	100
IWM resource center web/video (national; invited)	1	na
USB Take Action webinar (national; invited)	1	100
USB Take Action podcast (national; invited)	1 (Apr 3)	na

Outreach Links:

Integrated Weed Management Center

https://integratedweedmanagement.org/index.php/2019/11/01/horseweed-management-start-right-now-with-iwm/

USB Take Action Webinar Series

https://u.osu.edu/osuweeds/2020/02/19/take-action-webinar-series-weed-herbicide-management/

Penn State Field Crop News

https://extension.psu.edu/cover-crops-an-effective-herbicide-resistance-management-tool