WATERHEMP MANAGEMENT WITH RESIDUAL HERBICIDES IN ESTABLISHED ALFALFA

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Introduction

Alfalfa (*Medicago sativa* L.) is one of the most important perennial forages in Northern regions of the USA. It provides a high yielding and quality forage as well as key ecosystems services as part of a rotation with annual crops. In addition, one of the under-valued services is weed-control as it has been documented that alfalfa stands can reduce weed populations if managed correctly (Clay and Aguilar, 1998; Goplen et al., 2017). However, waterhemp (*Amaranthus tuberculatus* (Moq.) J. D. Sauer), one of the most troublesome weed species in the Midwestern United States, appears to be able to thrive within alfalfa production systems as established alfalfa fields are currently being invaded by this weed.

While waterhemp has been present in Wisconsin for over 150 years, it has only recently expanded its range in Wisconsin. At present, it can be found in over 80% of our counties, with 40% of the observations being reported in the last 4 years (Renz, 2018). Several factors are likely responsible for its rapid spread, including its biology (e.g. high fecundity, rapid growth rate), ecology (e.g,. discontinuous emergence pattern) and high propensity to develop resistance to herbicides. Currently, some of the waterhemp herbicide resistant populations found throughout the Midwest include resistance to glyphosate, acetolactate synthase-, photosystem II-, 2,4-D, protoporphyrinogen (PPO), or 4-hydroxyphenylpyruvate dioxygenase (HPPD)-inhibiting herbicides (Heap 2018). Furthermore, several multiple-herbicide resistant populations have been reported in the Midwest (Schultz et al., 2015).

Although it has been reported that waterhemp can germinate under established plant canopies (Steckel et al., 2003) and produce viable seed (Wu and Owen, 2014), there is a lack of information on these patterns in established alfalfa fields. Additionally, it is not known what the impact of waterhemp invasions have on forage quality, productivity and resulting milk production from established alfalfa fields. Weeds harvested often increase yields and can be utilized as a forage, but reduce forage quality (Cosgrove and Barrett, 1987). While recent research suggests the level of reduction can be offset by the added biomass in milk production, weed biomass must be a minor component (<15%) of the total forage biomass (Renz et al., 2018). Moreover, water-hemp may impact alfalfa stand density which could reduce long-term alfalfa stand life.

Even though several herbicides registered for use in established alfalfa (e.g. acetochlor, flumioxazin, metribuzin, and pendimethalin) have been documented to have success in controlling waterhemp in other crops, it is not clear when to apply each product to maximize season-long control of waterhemp in established alfalfa. Given that

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little is known about the impacts and control of this species in established alfalfa, the objectives of this study were to determine the impacts of waterhemp on alfalfa productivity and quality; the effectiveness of management strategies based on residual herbicides applied at different timings; and (iii) waterhemp's emergence patterns and ability to produce seeds in established alfalfa cropping systems.

Material and Methods

The trial was conducted on a commercial established second-year alfalfa field, located in Omro, Wis. from June to September 2019. The experimental design was a randomized complete block design with four replications. Plots were three meters wide and nine meters long. Treatments consisted of all possible combinations of two application timings (after the first [06/03] or second cut [07/07] of the growing season); and three residual herbicide treatments (acetochlor at 1.7 kg ai ha^{-1}, flumioxazin at 140 g ai ha^{-1} and pendimethalin at 2.13 kg ha^{-1}). A sequential application of acetochlor at 1.7 kg ha^{-1} (after first cut) followed by flumioxazin at 140 g ha^{-1} (after second cut) was also included, resulting in 7 different herbicide treatments plus an untreated control. Rates were based on soil type and on the maximum rate provided on the labels. Treatments were applied with a CO_2-pressurized backpack boom sprayer equipped with eight 11002 flat-fan nozzles at a pressure of 276 kPa and an application volume of 187 L ha^{-1}.

Waterhemp control and alfalfa selectivity were determined quantitatively at the second, third, and fourth harvest of the season by randomly tossing three 0.5 m^2 quadrats in each plot and harvesting all above ground plant material within the quadrat. Forage was combined into one sample and separated into waterhemp, other weeds, and alfalfa. Samples were dried until constant mass was achieved and weighed. In addition, alfalfa stem density was measured by randomly placing three 0.25 m^2 quadrats within each plot in the fall after the last harvest. Measurements occurred when alfalfa stems were between 15 and 25 cm tall following methods summarized by Undersander et al. (2011). Furthermore, waterhemp control was also determined qualitatively by visually estimating the percentage of waterhemp at different phenological stages (i.e. vegetative, flowering, or with fruit present) at each harvest interval. Finally, forage quality was estimated for each plot at each harvest interval. Plant categories were combined for each plot at each harvest, ground and then sent to UW USDA Laboratory for Near-Infared Reflectance Spectroscopy (NIRS) analysis.

Statistical analyses were performed using the open-source statistical software R 3.4.3 (R Core Team 2014). All response variables were subjected to ANOVA to test for herbicide treatment effects. Treatments were considered different when $P \leq 0.05$. Means were separated using Fisher's LSD test ($\alpha = 0.05$) when appropriate. When necessary, data were square root transformed to stabilize error variances; however, original values are reported.

Results

Results indicated that herbicide treatments had no impact on alfalfa biomass at any harvest interval or when summed across all three (Table 3-4). Additionally, while no waterhemp biomass was observed in the second cut, all treatments decreased waterhemp biomass during the third harvest (Table 3). Acetochlor applied on 6/3 and flumioxazin applied on both timings provided ≥ 90% biomass reduction (Table 3). At the fourth harvest, acetochlor (6/3) and the sequential application of acetochlor (6/3) followed by flumioxazin (7/7) were the only treatments that continued to provide >90% waterhemp biomass suppression as all herbicides applied on 7/7 provided ≤ 77% waterhemp suppression (Table 4). The most effective treatments for total season waterhemp biomass production were acetochlor applied on 6/3 (94% reduction) and acetochlor + flumioxazin (94% reduction). These were followed by flumixazin and acetochlor (86 and 82% reduction, respectively) both applied on 7/7 (Table 4). Moreover, despite the herbicides and frequent harvests, waterhemp plants were able to produce viable seeds after the fourth harvest in all treatments (September) (Table 5).

Initial Conclusions

Alfalfa yields were not affected, by the waterhemp populations at any time throughout the study. While large germination events occurred (> 100 plants/m^2), many of the plants died or were not able to compete with the established alfalfa plants. It is not known if higher densities and different conditions would result in reduced alfalfa biomass, and further research is required to confirm these results. While alfalfa forage biomass may not be impacted reductions in forage quality may occur, especially in the 4th harvest when waterhemp plants are mature and consist of mostly stems. The amount of waterhemp required to reduce forage quality is currently under investigation. While successful control of waterhemp (> 90% biomass reduction) was observed with select treatments, seeds were still produced in these treatments. Thus, alternative approaches will be required to assure waterhemp seed bank reductions. Knowledge of the resistance status of waterhemp populations will be critical in developing these strategies as few herbicides exist that do not have resistant waterhemp populations in the United States. Additional research at different sites is needed to validate these findings.

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Table 1. Treatment information.

TRT	Trade name	Active ingredient	Rate (kg ai ha^{-1})	Application timing	MOA	Manufacturer
1	Untreated	-	-	-	-	-
2	Warrant	acetochlor 359 g ai L^{-1}	1.70	06/03	Group 15; VLCFA synthesis inhibitors	Bayer
3	Chateau	flumioxazin 51%	0.14	06/03	Group 14; PPO inhibitor	Valent
4	Prowl H_2O	pendimethalin 455 g ai L^{-1}	2.13	06/03	Group 3; Microtubule assembly inhibition	BASF
5	Warrant	acetochlor 359 g ai L^{-1}	1.70	07/07	Group 15; VLCFA synthesis inhibitors	Bayer
6	Chateau	flumioxazin 51%	0.14	07/07	Group 14; PPO inhibitor	Valent
7	Prowl H_2O	pendimethalin 455 g ai L^{-1}	2.13	07/07	Group 3; Microtubule assembly inhibition	BASF
8	Warrant[1] + Chateau[2]	Acetochlor[1] + flumioxazin[2]	1.7 + 0.14	Both	Group 15 + Group 14	-

[1] Applied at 06/03; [2] Applied at 07/7

Table 2. Period between herbicides application (both timings) and study assessments.

TRT	Active ingredient	Rate (kg ai ha^{-1})	Application timing	Second cut	Third cut	Fourth cut	Alfalfa stand count
1	-	-	-	-	-	-	-
2	acetochlor 359 g ai L^{-1}	1.70	06/03	24 DAT	53 DAT	88 DAT	115 DAT
3	flumioxazin 51%	0.14	06/03	24 DAT	53 DAT	88 DAT	115 DAT
4	pendimethalin 455 g ai L^{-1}	2.13	06/03	24 DAT	53 DAT	88 DAT	115 DAT
5	acetochlor 359 g ai L^{-1}	1.70	07/07	-	19 DAT	54 DAT	81 DAT
6	flumioxazin 51%	0.14	07/07	-	19 DAT	54 DAT	81 DAT
7	pendimethalin 455 g ai L^{-1}	2.13	07/07	-	19 DAT	54 DAT	81 DAT
8	acetochlor + flumioxazin	1.7 + 0.14	Acetochlor (6/3) + flumioxazin (7/7)	-	-	-	-

Table 3. Herbicide effects for alfalfa, waterhemp and other weeds biomass prior to the second and third cut of the season in an established alfalfa field located at Omro, Wis., 2019.

Treatments	Second cut			Third cut		
	Alfalfa	Waterhemp	Other weeds[1]	Alfalfa	Waterhemp[3]	Other weeds[1]
	………………………… kg DM ha^{-1} …………………………					
Untreated	1,987.8	0	7.5	1,852.7	55.6 a	1.8
acetochlor (06/03)	1,952.5	0	0	1,839.7	3.9 def	1.3
flumioxazin (06/03)	1,728.7	0	0	1,687.6	3.0 ef	1.7
pendimethalin (06/03)	1,954.1	0	13.1	1,910.6	6.4 c	6.5
acetochlor (07/07)	-	-	-	1,520.4	5.6 cd	8.6
flumioxazin (07/07)	-	-	-	1,533.4	2.0 f	28.4
pendimethalin (07/07)	-	-	-	1,652.1	47.2 b	2.5
acetochlor + flumioxazin	-	-	-	1,188.4	4.3 cde	10.9
P-value	0.450	-	0.242	0.376	<0.001	0.301

[1] Mainly fall panicum and dandelion; [2] Means within alfalfa cuts, plant classes and columns followed by the same lowercase letter are not significantly different according to Fisher's LSD test at $P \leq 0.05$. [3]Data were square root transformed for mean separation, but raw means are presented for easier clarification.

Conclusions

Clearly the relationship between TP and DP FWMC differs by environmental condition (frozen or unfrozen). Tillage, soil test P, and manure application were all influential aspects of TP and DP loss, but the magnitude of the influence differed between frozen and non-frozen conditions. Interestingly, inherent soil factors such as slope, texture, and drainage class were not influential based on regression tree analysis. These results confirm the conventional wisdom related to tillage, manure application, and soil test P, although no-till did not result in lower P losses during frozen conditions. Pasture also had much higher P losses than expected. More work is needed to understand that effect. But collectively, this work, along with further analysis, can lead to a greater understanding of the relative influence of factors that drive P loss. This analysis would suggest that reducing soil test P would be the first step to reduce P loss, followed by reduction in tillage.

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