Sustainable Management of Waterhemp in Established Alfalfa for Dairy Systems

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Abstract:

No information is available on the impact of waterhemp in established alfalfa systems. Waterhemp is highly competitive but the fast growth of alfalfa and frequent harvests may limit the impact. We sought to determine the impact of waterhemp in established alfalfa. We measured the timing of waterhemp emergence, seed production and if control can be achieved with residual herbicides. Five field trials across three states were established between 2019 and 2021. Results found few waterhemp plants in established alfalfa when alfalfa plant density was high, despite large amounts of viable seed in the soil. Waterhemp emergence began near the first harvest and continued throughout the season. Waterhemp did not compete well with alfalfa as biomass was < 5% of the total forage production and many died (>70%). Acetochlor was effective at reducing waterhemp biomass if applied after either the 1st or 2nd cut. While biomass was reduced >90%, forage production and forage quality were similar with not treated controls. A small amount of seed was produced at two locations (<100 seeds/m2). Acetochlor reduced but did not eliminate the amount of seed. Results support the notion that waterhemp has no impact to established alfalfa productivity or quality.

Keywords: Waterhemp, established alfalfa, acetochlor, flumioxazin, pendamethalin

INTRODUCTION

This project was established to determine the impact of waterhemp and palmer amaranth on established alfalfa managed for dairy systems. While palmer amaranth and waterhemp have been documented to be spreading throughout the Midwestern and Eastern United States, impacts to crops have been only documented to annual systems. Corn and soybean yields have been reduced from these weeds despite the additional management efforts employed. Increases in herbicide resistance is of main concern, as these species appear well adapted to evolving resistance, often with populations evolving resistance to multiple modes of action of herbicides.

However, no information is available on the impact of these weeds in perennial forage systems like alfalfa. While alfalfa is likely at risk from these species during the establishment phase, the impacts in subsequent years has not been examined. Waterhemp and Palmar amaranth are

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highly competitive but the fast growth of established alfalfa and frequent harvests may limit the impact of these species. Given that alfalfa grown in dairy systems is harvested more frequently and managed more intensively than when grown for other uses, alfalfa production may have reduced to no impacts from waterhemp or palmer amaranth.

We sought to understand the impact of these species in established alfalfa. In addition to this we also were interested in evaluating the emergence timing of seedlings. Targeted management in established alfalfa likely would involve residual herbicides as it is common that these weeds are resistant to most POST options. Knowledge of when the majority of seedlings emerge would help optimize herbicide application timing and effectiveness. Additionally, we sought to understand the level of seed production of these weeds and if additional management through the use of residual herbicides in established alfalfa would eliminate weed seed production. This information will be extremely valuable as many producers are now relying on the alfalfa rotation to bring herbicide resistant waterhemp/palmer populations down to levels that they can then control when they rotate to annual crops (corn/soybeans). To answer these questions, we established four field experiments in 2019. Due to lack of establishment of weeds in multiple locations (see below) we repeated experiments in 2021.

Project Objectives and Corresponding Results (see example below):

Specific Objectives

PROJECT OBJECTIVES	**CORRESPONDING RESULTS**
Determine the optimal timing to apply residual herbicides in spring to maximize waterhemp control	Applications after either the 1st or 2nd cut were effective, but due to the high level of mortality of plants after the first cut we recommend applications after the second cut
Determine how treatments/timing influence alfalfa quality and yield.	None of the treatments improved alfalfa quality and yield. Flumioxazin treatments did cause substantial injury (>25% reduction biomass) 33% of the time it was sprayed.
Quantify if effective waterhemp control from residual herbicides can alleviate the impact on forage quantity and quality.	Presence of waterhemp in forage biomass was minimal (<5%) and did not reduce forage quality.
Evaluate if waterhemp seeds are produced in an alfalfa field that is managed for dairy production, and if any residual herbicide treatments/timings prevent seed production.	Waterhemp seed production did occur in two of the fields, but seed production was near zero (74 seeds m^{-2}). Management further reduced seed production but did not eliminate.

MATERIALS AND METHODS

On-farm established alfalfa fields with known populations of waterhemp/palmer amaranth were located and trials were established in 2019 in each of the four states (MN, MI, PA, WI). Treatments were established at each site and herbicides (acetochlor, flumioxazin, or pendimethalin) were applied at maximum labeled rates just after (within 7 days) either the first or second harvest of 2019. In 2019 only one location (Wisconsin) had sufficient waterhemp/palmer to measure the effect on alfalfa production. Due to this, experiments were replicated in 2021 and in each state. See table 1 for details of each site.

Table 1. Locations for established alfalfa trials in Wisconsin, Michigan, Minnesota, and Pennsylvania in 2019 and 2021.

State	Year	Nearest City	species	Comments
Wisconsin	2019	Omro	Waterhemp	Low alfalfa plant density (29 stems ft^{-2}), high waterhemp population
Minnesota	2019	Little Rock	Waterhemp	No waterhemp present in 2019, despite large amounts in the establishment year (2018).
Michigan	2019		Palmer	No Palmer amaranth present in 2019, despite large amounts in the establishment year (2018).
Pennsylvania	2019	Bellefonte	Palmer	No Palmer present in 2019, despite large amounts in the establishment year (2018).
Wisconsin	2021	La Farge	waterhemp	High alfalfa plant density (67 stems ft^{-2} ; no precip for 3 wks after 1st cut
Minnesota	2021	Rosemont	Waterhemp	No waterhemp detected after the first cut despite high levels the previous year (384 plants/m2). Lack of substantial rainfall in June and July a contributing factor (2" rain in June and 1" in July) , but waterhemp still did not emerge in August when rainfall returned to normal levels
Michigan	2021		Palmer amaranth	Palmer amaranth observed emerging after the second cut
Pennsylvania	2021	Rock Springs	Waterhemp	Moderate alfalfa plant density (47 stems ft^{-2})

Measurements:

Alfalfa stem density was estimated in the spring prior to applying the treatments. Weed control and alfalfa injury were estimated and forage yield was taken within each treatment just prior to harvests 2, 3, and 4. Forage quality was estimated at one site. Milk production was not estimated as no differences in yield were found. Instructions on the use of MILK2016 model clearly state to not utilize this tool if differences in yield do not exist. (Undersander et al. 2016).

RESULTS AND DISCUSSION

2019: Only one location had waterhemp present to evaluate its impact on alfalfa. At this location waterhemp density in areas not treated averaged 144 plants m^{-2} just after the first harvest. Plant density decrease substantially after each harvest, and by September waterhemp density was only 12 plants m^{-2} (92% reduction) (Figure 2). Over 50% of all waterhemp plants emerged just prior to the first harvest. While an application of acetochlor after the first or second cut reduced seasonal waterhemp biomass by

82-94%, these did not improve alfalfa yield or stem density (tables 2 and 3). Not-treated areas had many waterhemp plants but did not produce a large amount of biomass in comparison to alfalfa, as waterhemp was < 5% of the overall alfalfa biomass. Due to this no differences in forage quality parameters resulted among any of the treatments (data not shown). These factors all demonstrate the limited impact waterhemp had on established alfalfa. Some of the plants did flower and produce seed in treated and not treated plots (data not shown). Since this data was from only one site, results needed to be replicated to verify this information.

Table 2. Herbicide effects for alfalfa, waterhemp and other weed biomass at the 2nd and 3rd cut of the season in an established alfalfa field located at Omro, WI, 2019.

Treatments	2nd Cut			3rd Cut		
	Alfalfa	Waterhemp	Other weeds[1]	Alfalfa	Waterhemp[3]	Other weeds[1]
	…………………………………. kg DM ha^{-1} …...					
Untreated	1,988	0	8	1,853	56 a	2
acetochlor (06/03)	1,953	0	0	1,840	4 def	1
flumioxazin (06/03)	1,729	0	0	1,688	3 ef	2
pendimethalin (06/03)	1,954	0	13	1,911	6 c	7
acetochlor (07/07)	-	-	-	1,520	6 cd	9
flumioxazin (07/07)	-	-	-	1,533	2 f	28
pendimethalin (07/07)	-	-	-	1,652	47 b	3
P-value	0.45	-	0.24	0.38	<0.01	0.30

[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 ≤ 0.05. [3]Data was square root transformed for mean separation, but raw means are presented for easier clarification.

Table 3. Herbicide effects for alfalfa, waterhemp and other weed biomass at the 4th cut and total season biomass in an established alfalfa field located at Omro, WI, 2019.

Treatments	**4th Cut**			**2nd, 3rd and 4th cuts sums**			**Alfalfa stand**
	Alfalfa	**Waterhemp[3]**	**Other weeds[1]**	**Alfalfa**	**Waterhemp[3]**	**Other weeds[1]**	
			………………………………… **kg DM ha^{-1}**	…………………………………			
Untreated	2,088	60 c	70	5,928	115 c	80	311
acetochlor (06/03)	2,112	3 e	0	5,904	7 f	1	344
flumioxazin (06/03)	1,961	146 a	28	5,378	149 a	30	319
pendimethalin (06/03)	1,888	134 b	42	5,753	141 b	61	288
acetochlor (07/07)	1,943	15 d	89	5,368	21 e	100	321
flumioxazin (07/07)	2,111	14 d	66	5,680	16 e	96	337
pendimethalin (07/07)	2,189	15 d	12	6,000	63 d	34	316
P-value	0.82	<0.01	0.16	0.60	<0.01	0.16	0.070

[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 ≤ 0.05; [3]Data was square root transformed for mean separation, but raw means are presented for easier clarification.

Figure 1. Waterhemp emergence pattern in established alfalfa just prior to each harvest (Omro, WI 2019) compared to typical emergence pattern in soybeans. Note the high level of emergence near the first harvest (>50%) compared to the delayed emergence in soybeans.

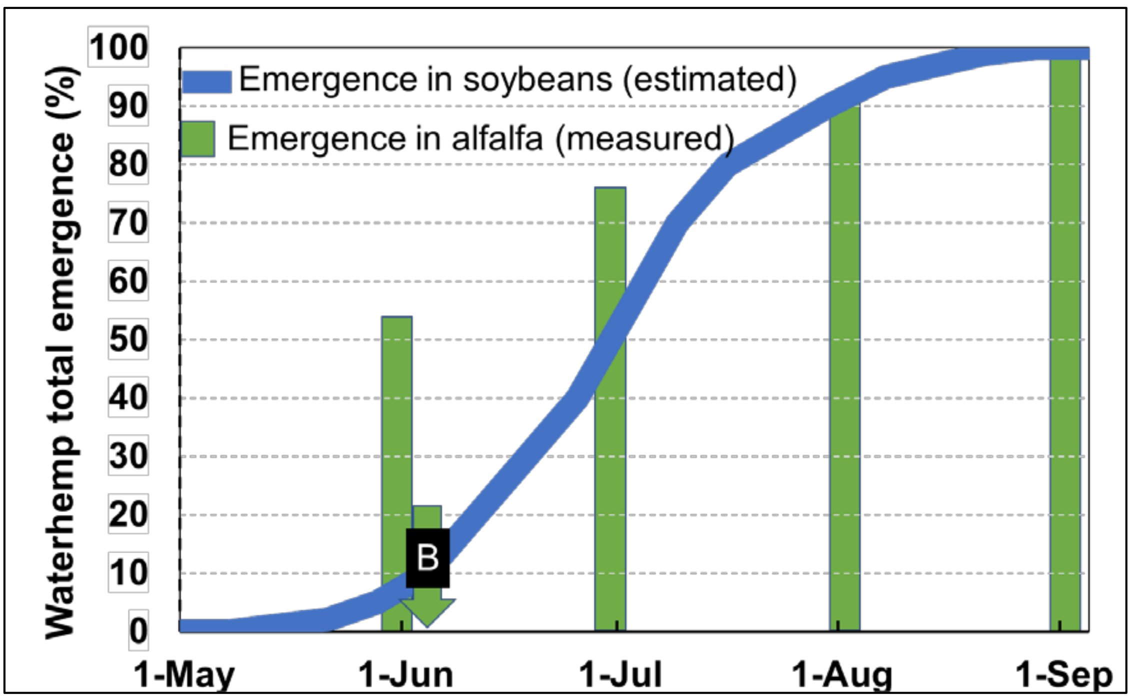
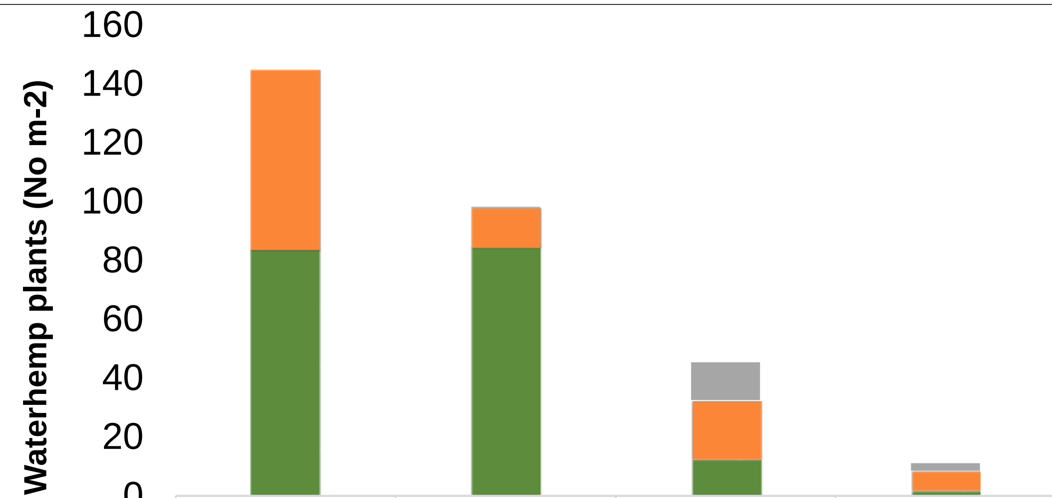


Figure 2. Waterhemp density in established alfalfa at each harvest (Omro, WI 2019). Note the high level of mortality (.90%) between June and September.



	June	July	August	September
Large	0	0	13	3
Medium	61	13	20	7
Small	84	85	13	2

2020: Due to the coronavirus outbreak none of the researchers were able to establish field research for this project. We asked and received an extension to conduct in 2021.

2021: Waterhemp was the focal weed species in Pennsylvania, Wisconsin and Minnesota and Palmer amaranth was in Michigan. No data was provided from the Michigan investigator therefore this report will focus on the waterhemp results only. The Minnesota site experienced a severe drought (< 2" rain in June and < 1" of rain in July). This resulted in little alfalfa regrowth after the second harvest therefore no yield data was taken after that timeframe. At this location no waterhemp plants were observed in the entire field with the exception of two plants just prior to the first cutting. This was a surprise as this field is known to have an extremely high waterhemp seedbank and open areas were present in the field due to poor alfalfa growth. Even when precipitation was normal in August no waterhemp emerged. In contrast waterhemp plants were common in Wisconsin and Pennsylvania. Waterhemp densities peaked at 30 plants m^{-2} in Pennsylvania and 23 plants m^{-2} in Wisconsin. We believe alfalfa plant density is strongly correlated to waterhemp density which is supported by the alfalfa stand density of each field. The 2021 Wisconsin site was well above the minimum threshold (67 stems ft^{-2}) and the Pennsylvania site was just at the accepted threshold (47 stems ft^{-2})) while the 2019 Wisconsin site (Omro) was well below the threshold (29 stems ft^{-2}). Alfalfa stem density in spring may be a major factor that determines waterhemp density. Emergence of waterhemp in Pennsylvania was similar to the 2019 Wisconsin site with 80 % emergence between the first and second harvest (Figure 3). In La Farge, WI (2021) waterhemp emergence was delayed, with emergence initiated at the 2^{nd} harvest. We believe this one-month delay was due to the lack of precipitation surrounding and after the 1st harvest (17 days with no precipitation). This delayed emergence of waterhemp until the next cutting.

Applications of acetochlor and flumioxazin just after the first or second harvest provided acceptable weed control in Pennsylvania in 2021 (Tables 6) but had no improvement on the forage productivity. In Wisconsin, we saw no impact of any of the herbicides on weed control (Tables 4,5). This is likely due to two factors, 1) the high stand density of the alfalfa, that prevented the development of substantial weed populations (waterhemp and/or other weeds) plus the lack of rainfall to activate the herbicide after application. Of note is that flumioxazin treatments did injure alfalfa stands and reduce yield 33% of the time when applied. While flumioxazin has been widely used for waterhemp control in annual cropping systems the added injury potential and resulting yield losses (>25%) will limit the use of this herbicide in established alfalfa systems. Thus 2021 results confirm that waterhemp did not impact established alfalfa productivity when present or when removed. In all experiments waterhemp was a small percentage of the overall biomass (<5%) and did not appear to compete effectively with alfalfa even when at high densities.

Similar to the 2019 study, waterhemp mortality was high from competition with alfalfa and the harvest schedule. In Wisconsin we estimated that 73% of emerged waterhemp plants died during the 2021 season. Of those that survived some did flower and produce a small amount of seed (20 m^{-2}) (data not shown). This seed production, while significant is much less than documented in annual cropping systems (1 plant can produce thousands of seed). While seed production was reduced by herbicide treatments in Wisconsin in 2021 it was not eliminated. In Pennsylvania, no seed was produced at the site. We hypothesize that this was due to waterhemp plants flowering at the time of the 4th harvest (9/6/21). After harvest plants did not resprout, suggesting that a later season harvest at that phenological stage may prevent production of viable seed. Further exploration of this observation is warranted.

CONCLUSIONS

Results across five field research trials across three states support the notion that waterhemp has no impact to established alfalfa productivity or quality. Presence of competitive alfalfa stands (>45stems ft^{-2}) is likely a key factor in preventing the establishment of significant amounts of waterhemp. Even when below this threshold, while large waterhemp populations can establish, mortality is high due to the competitiveness of the alfalfa and frequent harvest schedule. Emergence of waterhemp in established alfalfa, while variable, begins near the first harvest if adequate soil moisture is present to promote germination. Applications of herbicides can reduce but not eliminate populations. Acetochlor gave the highest control with no injury to alfalfa. While management of waterhemp did not improve productivity of quality, interest in management may be warranted to further reduce waterhemp populations to a manageable level in annual crops. If interested in additional applications we suggest acetochlor be applied after the 2nd harvest, as it reduced seed population to minimal amounts in two studies (WI 2019, PA 2021). While waterhemp is an aggressive and competitive weed, established alfalfa is an effective competitor with this plant, and can flourish and produce high yields without impacting forage quality, even under high populations of this annual pest.

Table 4. Herbicide effects for alfalfa, waterhemp and other weeds biomass prior 2nd and 3rd cut of the season in an established alfalfa field located at La Farge, WI, 2021.

Treatments	2nd Cut			3rd Cut		
	Alfalfa	Waterhemp	Other weeds[1]	Alfalfa	Waterhemp[3]	Other weeds[1]
	………………………………… kg DM ha^{-1} ………………………………………					
Untreated	3,311	0	9	2,078 a	0	8
acetochlor (06/01)	3,398	0	0	2,098 a	0	0
flumioxazin (06/01)	3,076	0	0	2,123 a	0	0
pendimethalin (06/01)	3,378	0	0	1,888 a	0	5
acetochlor (07/03)	-	-	-	2,164 a	0	0
flumioxazin (07/03)	-	-	-	674 b	0	0
pendimethalin (07/03)	-	-	-	2,084 a	0	4
P-value	NS	-	0.242	<0.01	NS	NS

[1] dandelion and lambsquarter; [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 ≤ 0.05. [3]Data was square root transformed for mean separation, but raw means are presented for easier clarification.

Table 5. Herbicide effects for alfalfa, waterhemp and other weeds biomass prior 4rd cut and total season biomass in an established alfalfa field located at La Farge, WI.

Treatments	4th Cut			2nd, 3rd and 4th cuts sums		
	Alfalfa	Waterhemp[3]	Other weeds[1]	Alfalfa	Waterhemp[3]	Other weeds[1]
	………………………………… kg DM ha^{-1} ………………………………………					
Untreated	1,668	8	10	7,050 ab	4	14
acetochlor (06/03)	1,557	22	0	7,080 ab	11	0
flumioxazin (06/03)	1,751	0	0	6,960 ab	0	0
pendimethalin (06/03)	1,754	0	1	7,020 a	0	3
acetochlor (07/07)	1,930	0	24	7,460 a	0	12
flumioxazin (07/07)	1,294	9	29	5,100 c	5	15
pendimethalin (07/07)	1,294	0	1	6,580 b	0	7
P-value	0.08	NS	NS	<0.01	NS	NS

[1]Mainly lambsquarter 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 ≤ 0.05; [3]Data was square root transformed for mean separation, but raw means are presented for easier clarification.

Table 6. Herbicide effects for alfalfa, waterhemp and other weeds biomass prior 2nd and 3rd cut of the season in an established alfalfa field located at Rock Springs, PA, 2021. Note that waterhemp and weed biomass was not separated from alfalfa, therefore data reported is combined across all plant classes.

Treatments	**Alfalfa + Weeds**			
	2nd cut	**3rd cut**	**4th cut**	**Sum 2+4th cut**
	………………………………. Mg DM ha^{-1} ……....................................			
Untreated	2.9 a	*	2.7	5.6 a
acetochlor (06/06)	2.9 a	*	2.7	5.6 a
flumioxazin (06/06)	1.3 b	*	2.5	3.8 b
pendimethalin (06/06)	3.0 a	*	2.8	5.8 a
acetochlor (07/01)	2.9 a	*	3.0	5.9 a
flumioxazin (07/01)	2.6 ab	*	2.3	4.9 ab
pendimethalin (07/01)	2.5 ab	*	1.9	4.4 ab
P-value	0.03	*	NS	0.03

[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 ≤ 0.05. [3]Data was square root transformed for mean separation, but raw means are presented for easier clarification.

* 3rd harvest samples were lost before biomass was weighed.

Table 7. Herbicide effects for alfalfa, waterhemp and other weeds biomass prior 2nd and 3rd cut of the season in an established alfalfa field located at Rosemont, MN, 2021. Note no alfalfa was harvested after the 2nd Cut due to severe drought. No waterhemp was viewed in any of the plots after 1st application.

Treatments	**2nd Cut**		
	Alfalfa[1]	**Waterhemp**	**Other weeds[2]**
	……………….. kg DM ha….........................		
Untreated	2,013	0	62
acetochlor (06/04)	2,019	0	22
flumioxazin (06/04)	1,803	0	0
pendimethalin (06/04)	2,259	0	18
acetochlor (07/11)	1,971	-	62
flumioxazin (07/11)	1,542	-	39
pendimethalin (07/11)	1,903	-	37
P-value (<0.05)	NS	NS	NS

[1] Alfalfa 2nd cut was harvested and herbicides applied two days after biomass samples were collected for the 07/09 treatments, so these are still untreated checks at this sample date.

[2] dandelion, lambsquarter, common lambsquarter, marestail, and woolly cupgrass. Occurrence of other weed species was so sporadic that no treatment differed at P≤0.05.

* No alfalfa was harvested due to lack of precipitation

Table 8. Herbicide effects for alfalfa, palmer amaranth and other weeds biomass prior 2nd and 3rd cut of the season in an established alfalfa field located at Lansing, MI, 2021. DATA NOT PROVIDED TO LEAD PI, please contact Erin Burns (burnser5@msu.edu) for results.

Treatments	2nd Cut			3rd Cut		
	Alfalfa	Waterhemp	Other weeds[1]	Alfalfa	Waterhemp[3]	Other weeds[1]
	………………………………. kg DM ha^{-1} …………………………………….					
Untreated						
acetochlor (06/01)						
flumioxazin (06/01)						
pendimethalin (06/01)						
acetochlor (07/03)						
flumioxazin (07/03)						
pendimethalin (07/03)						
P-value						

[1] dandelion and lambsquarter; [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 ≤ 0.05. [3]Data was square root transformed for mean separation, but raw means are presented for easier clarification.

Table 9. Herbicide effects for alfalfa, palmer amaranth and other weeds biomass prior 4rd cut and total season biomass in an established alfalfa field located atLansing, MI, 2021. DATA NOT PROVIDED TO LEAD PI, please contact Erin Burns (burnser5@msu.edu) for results.

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Treatments	4th Cut			2nd, 3rd and 4th cuts sums		
	Alfalfa	Waterhemp[3]	Other weeds[1]	Alfalfa	Waterhemp[3]	Other weeds[1]
	………………………………. kg DM ha^{-1} …………………………………….					
Untreated						
acetochlor (06/03)						
flumioxazin (06/03)						
pendimethalin (06/03)						
acetochlor (07/07)						
flumioxazin (07/07)						
pendimethalin (07/07)						
P-value						

[1]Mainly lambsquarter 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 ≤ 0.05; [3]Data was square root transformed for mean separation, but raw means are presented for easier clarification.

Figure 3. Waterhemp emergence pattern in established alfalfa at Omro, WI (2019), La Farge, WI (2021) and Rock Springs, PA (2021). Note the majority of waterhemp seedlings emerged between the 1st and 2nd cut. Rosemont, MN data was excluded due to no waterhemp emergence. Michigan data was not provided.

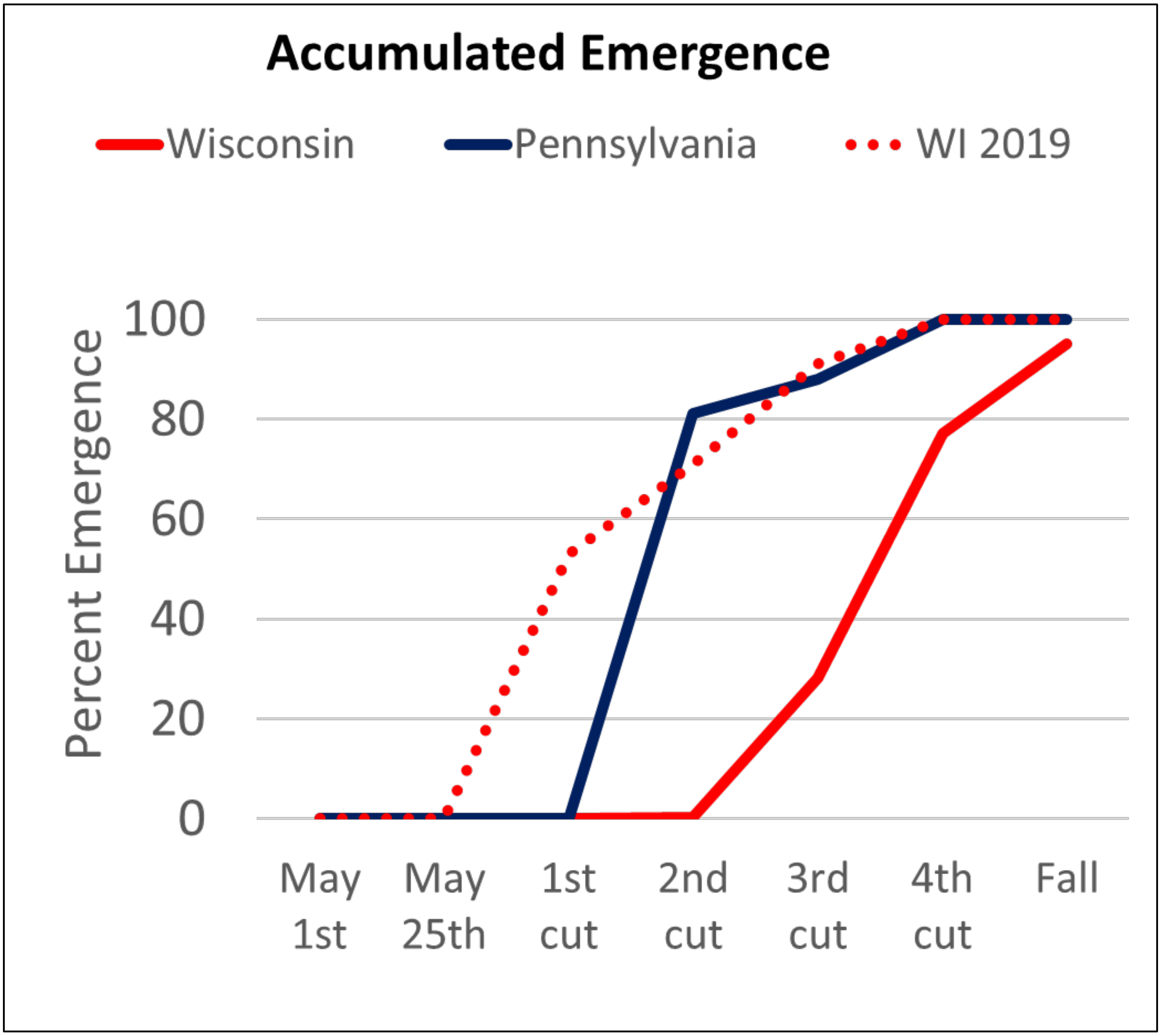


Figure 4. Precipitation patterns at Omro, WI (2019), La Farge, WI (2021) and Rock Springs, PA (2021). Note the lack of rainfall at La Farge immediately after the 1st cut. This likely influenced waterhemp emergence and herbicide activation. Rosemont, MN data was excluded due to no waterhemp emergence. Michigan data was not provided.

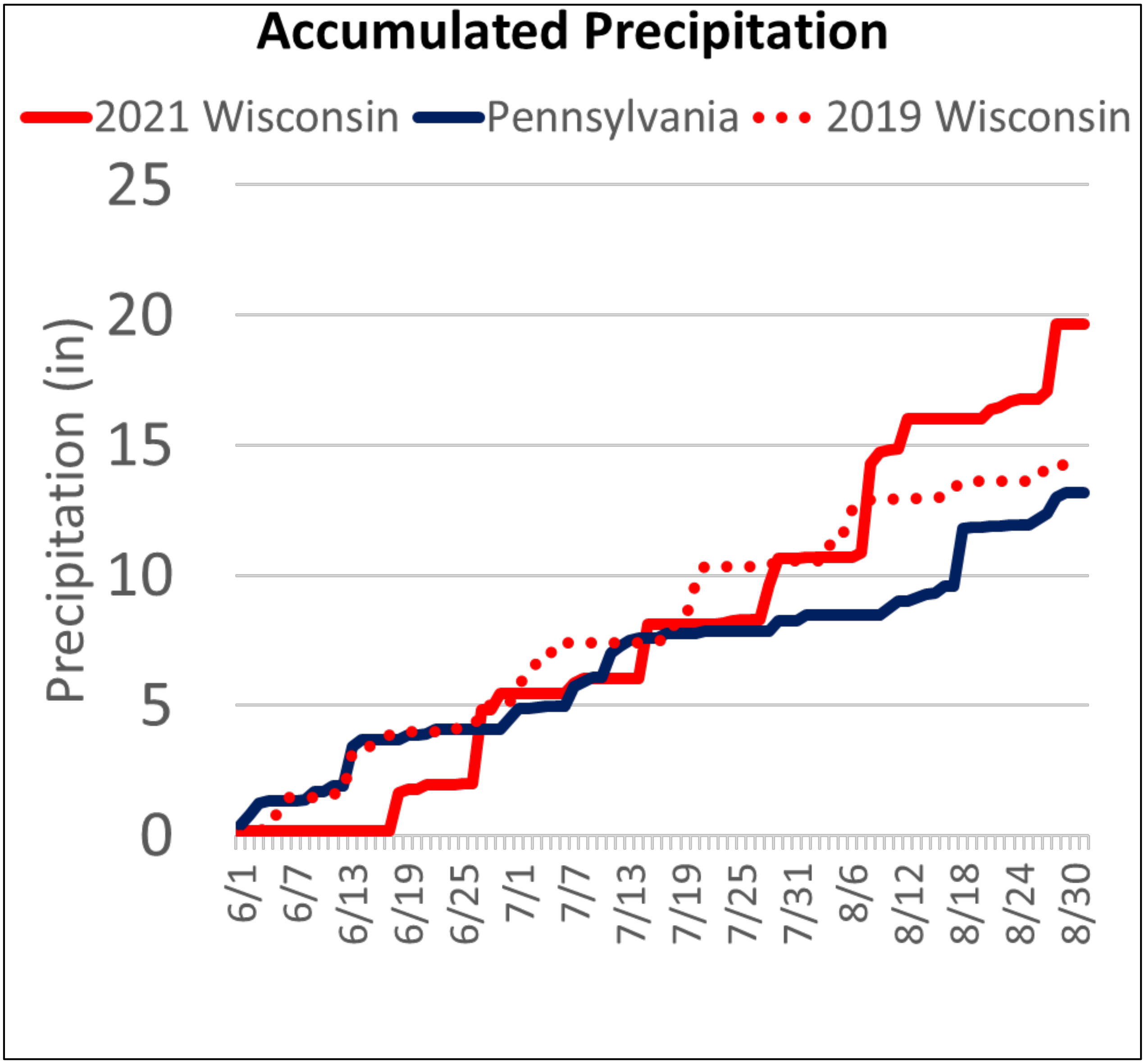
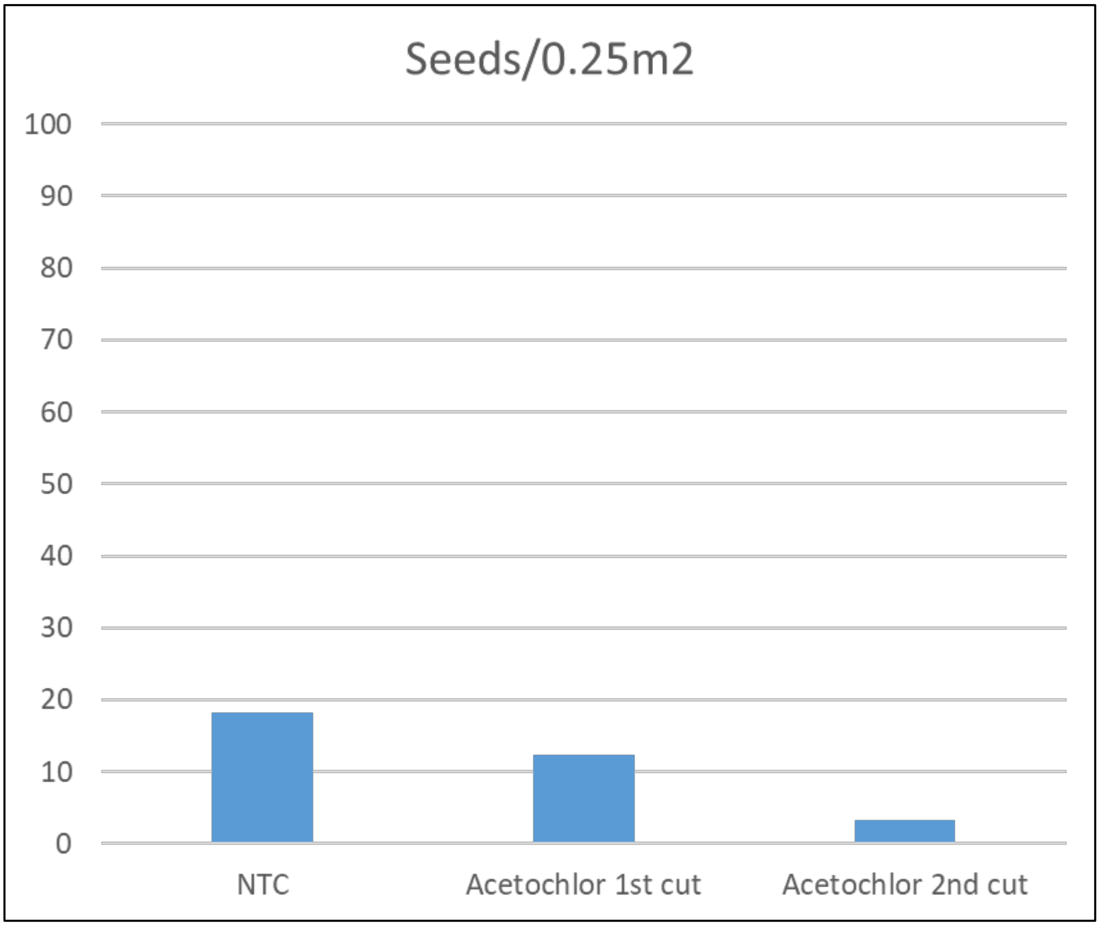


Figure 5. Seed production of waterhemp plants in established alfalfa in not treated and treatments utilizing acetochlor at La Farge, WI (2021). While waterhemp plants were flowering at Rock Springs, PA (2021), none resprouted and produced any viable seeds at this location.



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